STATE COLLEGE OF WASHINGTON

AGRICULTURAL EXPERIMENT STATION

Pullman, Washington

Division of Agronomy
Soils Section

The Effect of Fertilizers on Crop Yields of Different Soils and on the Composition of Certain Crops

by

S. C. Vandecaveye and G. O. Baker

Bulletin No. 274

August, 1932

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By S. C. Vandecaveye and G. O. Baker*

A Progress Report of a Cooperative Fertilizer Plot Project

INTRODUCTION

In the spring of 1926 a number of fertilizer experiments were started to study the effect of fertilizers on the yield and composition of crops grown on different soils in western Washington. These experiments were carried on in cooperation with Smith-Hughes agricultural teachers who supervised the work in the field. It was the beginning of what later developed into an extensive state-wide fertilizer plot project for the purpose of ascertaining the fertility requirements of many different soils and of studying the effect of fertilizers on the composition of certain crops, notably the forage crops. The project was initiated by the Soils Section of the Division of Agronomy of the agricultural experiment station, and was carried on under its direction in cooperation with individual farmers on whose land the experiments were established, the Agricultural Extension Service, the State Board for Vocational Education, various commercial fertilizer companies, principally the Chilean Nitrate of Soda Educational Bureau and the Agricultural and Scientific Bureau of the N. V. Potash Export My., Inc., both of New York, and the Agricultural Department of various railroad companies. This report presents a summary of the results obtained during the years 1926 to 1931, inclusive.

* The authors wish to acknowledge their indebtedness to the late H. F. Holtz, Associate in Soils, for valuable assistance in planning and directing the project; to Clay A. Whybark for his assistance in obtaining the data on the pasture fertilizer experiments and the analytical results in the laboratory; to the Chilean Nitrate of Soda Educational Bureau, New York, for the fellowship grant and for other financial assistance for field expenses and the purchase of fertilizers in 1929 and 1930; to the Agricultural Bureau of the N. V. Potash Export My., Inc., New York, for financial assistance in the pasture fertilizer experiments and in the purchase of fertilizers in 1931; to all the County Agents and Smith-Hughes Agricultural teachers whose names appear in this report for their valuable assistance in supervising the field experiments and in obtaining yields and other necessary data; to all the farmers whose names appear in this report for supplying the land for the experiments; to the American Cyanamid Company, New York, the Fertilizer Department of the Anaconda Copper Mining Company, Chicago, and the Wilson and George Meyer Company, San Francisco, for supplying fertilizers in 1931; to the Agricultural Department of the Northern Pacific Railway Company for free transportation of the fertilizer materials in 1931; and to the Clearwater Lime Products Company, Orofino, Idaho, for supplying the lime needed for the experiments in 1930.

HISTORY AND PLANS OF THE EXPERIMENTS

The experimental plan in 1926 included superphosphate, muriate of potash, and lime treatments singly and in combinations, making eight-plot trials. The arrangement of the plots and the rates of application of the fertilizers are illustrated in Figure 1. Fertilizers for 25 of these experiments were shipped in the spring to Smith-Hughes agricultural teachers in western Washington. The same plan was followed in 1927, but fertilizers for only eight experiments were sent to the cooperators. Nitrogen was not included these first two years because one of the chief objects of the experiments at that time was to ascertain the effect of lime, and of phosphate and potash fertilizers on the yields, and on the phosphorus, calcium, and potassium content of the crops.

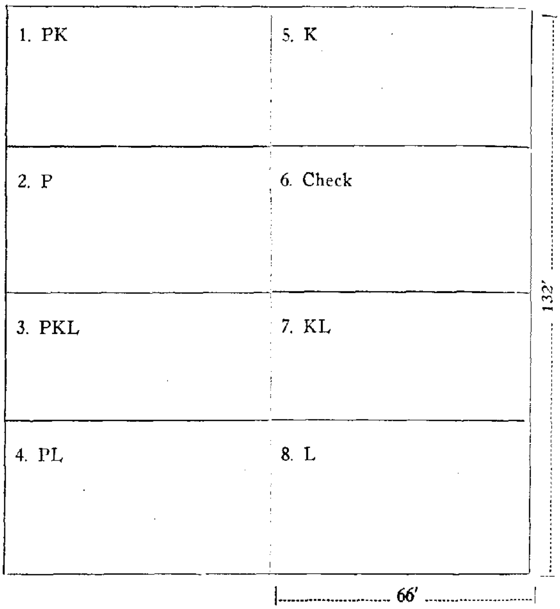


Fig. 1. Plan for Eight-Plot Experiments

Rate of application per acre

Superphosphate (P) ....500 lbs.
Muriate of Potash (K) ....150 lbs.
Agr. Lime (L) ....2000 lbs.

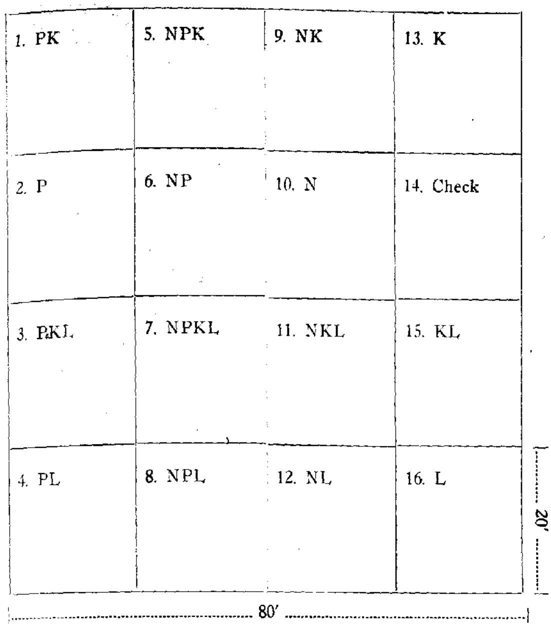


Fig. 2. Plan for 16-Plot Experiments

Rate of application per acre

Nitrate of Soda (N)	300 lbs.
Superphosphate (P)	600 lbs.
Sulfate of Potash (K)	270 lbs.
Agr. Lime (L)	4000 lbs.

In 1928 a nitrogen carrier was included for about one-half the number of experiments, and sulfate of potash was substituted for muriate of potash. The addition of nitrogen resulted in 16-plot trials including treatments with nitrate of soda, superphosphate, sulfate of potash, and lime, alone and in various combinations. The arrangement of the plots and the rates of fertilizer applications are shown in Figure 2. The main purpose of this plan was to study the fertility requirements of different soils in addition to the effect of the fertilizers on yield and on composition of the crops. Sufficient material for a

total of 30 experiments was sent to the cooperators in the spring. Although the 16-plot trials were much more complete than those previously established, they proved complex and difficult to handle in the field. Therefore, no new experiments of this kind were undertaken after 1930.

Early in 1929 the Chilean Nitrate of Soda Educational Bureau, New York, established a research fellowship to further this project, thus making it possible to enlarge greatly the number of trials and extend the work over the entire state. At this time the Agricultural Extension Service was added to the list of cooperators.

The experience and information gained during the first three years had clearly demonstrated the need for separate determinations of the

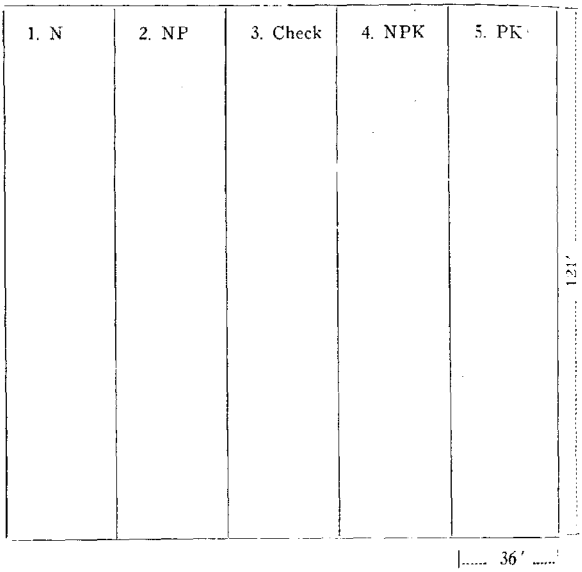


Fig. 3. Plan for Five-Plot Experiments

Rate of application per acre
Nitrate of Soda (N) .... 300 lbs.
Superphosphate (P) .... 600 lbs.
Sulfate of Potash (K) .... 200 lbs.
Agr. Lime (L) ....2000 lbs.

fertility requirements of a large variety of agricultural soils in the state and the advisability of simplifying the trials as much as possible without materially impairing the value of the results. Accordingly, two additional plans were devised, one for the fertilization of general farm crops, and the other for the fertilization of wheat in that section of eastern Washington where the annual rainfall is 18 inches or more.

The first plan consisted of a five-plot experiment including an untreated plot serving as a control; a nitrate of soda plot; a nitrate of soda and superphosphate plot; a nitrate of soda, superphosphate, and sulfate of potash plot; and a superphosphate and sulfate of potash plot, arranged as indicated in Figure 3, where the rate of application of fertilizers is also shown.

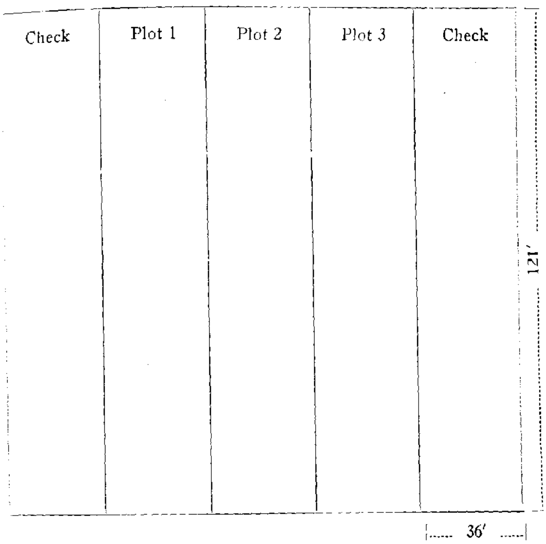


Fig. 4. Plan for Experiments on Wheat

Rate of application per acre

Plot 1.—150 lbs. Nitrate of Soda
Plot 2.—250 lbs. Nitrate of Soda
Plot 3.—350 lbs. Nitrate of Soda

Since available nitrogen is known to be a limiting factor in the exposed yellow subsoil of the hilltops of that section of the Palouse country where the annual rainfall is 18 inches or more, the fertilizer experiments for those soils were designed to determine the rate of application of nitrogen fertilizer that would give the most economical returns. Thus, the second plan consisted of experiments including two control plots and three plots receiving various amounts of nitrate of soda as shown in Figure 4.

In the early spring of 1929 sufficient fertilizers for a total of 112 experiments were shipped to the cooperators. After obtaining one year's results, it became evident that the five-plot experiments established in 1929 would not adequately show the fertility requirements of certain soils in western Washington, and in 1930 it was decided to

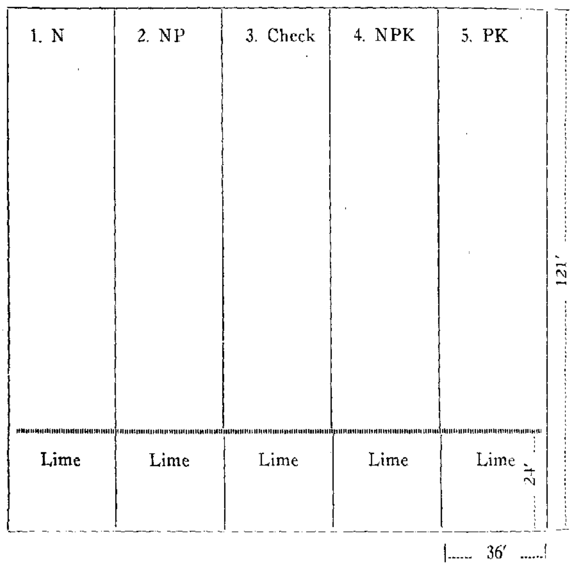


Fig. 5. Plan for Five-Plot Experiments with Addition of Lime

Rate of application per acre

Nitrate of Soda (N) .... 300 lbs.
Superphosphate (P) .... 600 lbs.
Sulfate of Potash (K) .... 200 lbs.
Agr. Lime (L) ....2000 lbs.

add lime to a strip across one end of the plots of some of the trials that were located on the more important agricultural soils. The rate of application of lime and the arrangement are shown in Figure 5. Sufficient fertilizers were shipped in the spring of that year for a total of 132 experiments, including 25 in which lime was applied.

In 1931 the Chilean Nitrate of Soda Educational Bureau found it necessary to withdraw its support, but it was possible to continue the project through the splendid cooperation of various other fertilizer companies and the Agricultural Department of the Northern Pacific Railway Company. Because of the greatly reduced funds available for the project it was necessary to reduce the size of the plots from one-tenth acre to one-twentieth acre in all the trials except the previously established 16-plot trials which originally were 400 square feet in area. This was done by decreasing the length of the plots from 121 feet to 60.5 feet. A slight change was made also in the five-plot experiments in that a superphosphate plot was added. This addition was made because many of the soils, especially those in western Washington, seemingly responded to phosphate fertilizers. The arrangement of this type of experiment and the rates of fertilizer applications are shown in Figure 6. Fertilizers for 90 experiments were shipped to the cooperators in the spring of that year.

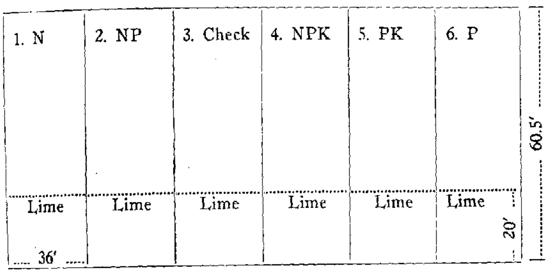


Fig. 6. Plan for Six-Plot Experiments with Addition of Lime

Rate of application per acre
Nitrate of Soda (N) .... 300 lbs.
Superphosphate (P) .... 600 lbs.
Sulfate of Potash (K) .... 200 lbs.
Agr. Lime (L) ....2000 lbs.

During 1929 the western representative of the Agricultural and Scientific Bureau of the N. V. Potash Export My., Inc., New York, established a series of six-plot pasture fertilizer experiments in six

different locations in western Washington. Through the courtesy of this bureau, a special grant was obtained in 1930 for the purpose of studying the effect of fertilizers on the yield and composition of pasture grass and hay. The yields of pasture cuttings and of hay were obtained in 1930 from a fenced-in strip across the plots, and the material was sent to the laboratory at Pullman for chemical analysis. The remaining part of the plots was accessible to livestock. A concept of the arrangement of the plots and of the rate of fertilizer applications may be gained from Figure 7.

The fertilizers for all the experiments were broadcast in the spring and mixed with the surface soil by harrowing or disking where

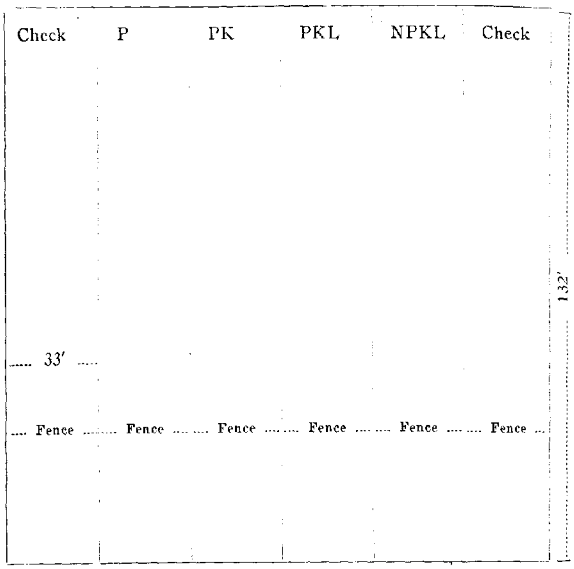


Fig. 7. Plan for Pasture Experiments

	Rate of application per acre 1929	1930
Ammonium Sulfate (N)	250 lbs.	125 lbs.
Superphosphate (P)	600 lbs.	300 lbs.
Muriate of Potash (K)	200 lbs.	100 lbs.
Hydrated Lime (L)	1000 lbs.	500 lbs.

spring crops were to be seeded. On the fall and perennial crops no special effort was made to work the fertilizer into the soil unless harrowing or disking happened to be a routine spring operation practiced by the cooperating farmer. In most cases yields were obtained from one or two representative 9 square feet areas and computed on an acre basis.

THE SOILS OF WASHINGTON

The soil is no longer regarded merely as a product of rock disintegration. It is also a product of climatic forces possessing qualities not necessarily related to the geological characteristics of the parent rock. Through the influence of climate, two distinctly different rock formations may yield strikingly similar soils, and similar rocks markedly different soils. Broadly speaking, Washington may be said to fall within two climatic zones, one west of the Cascades where the precipitation is abundant and the variations in temperature comparatively small, and the other east of the Cascades where the precipitation ranges from that of arid to that of semi-arid areas and where the extremes in temperature are considerably greater. Because of the great variations in climate, the soils in the state would be expected to differ greatly. A cursory examination reveals marked differences in soils of similar texture from similar rocks, but formed in these two distinct climatic zones. Thus, a silt loam from western Washington contains 0.6 per cent calcium, 0.09 per cent phosphorus, and 1.2 per cent potassium, whereas a silt loam from eastern Washington, derived from a similar rock formation, contains twice as much calcium or 1.21 per cent, considerably more phosphorus or 0.11 per cent, and more potassium or 1.9 per cent. The heavy rainfall in western Washington, resulting in rather severe leaching and weathering, has reduced the quantities of mineral plant nutrients in the soil, leaving an accumulation of iron and aluminum in the upper layers. The limited rainfall in eastern Washington has resulted in less leaching and weathering, and has left the soil richer in mineral plant nutrients and relatively lower in iron and aluminum. Thus, the soils of Washington naturally fall within two large divisions: the leached, thoroughly weathered soils of western Washington, and the arid and semi-arid soils of eastern Washington which have been subjected to only a small or moderate amount of leaching and weathering.

Western Washington Division

For convenience and facility in the interpretation of the results discussed in this report, the soils of western Washington have been subdivided arbitrarily according to the nature of the parent material from which they are derived and according to mode of formation. For instance, most of the soils in the Puget Sound Basin are derived

from glacial material, whereas most of those in southwestern Washington are derived from residual material. Some of these soils have been formed in place (in situ) and others have been formed from rock material that was transported by water. These factors were used as a means of classification and the following groups of soils designated:

1. Upland soils derived from glacial material
2. Terrace soils derived from glacial material
3. Lowland soils derived from glacial material
4. Upland soils derived from residual material
5. Terrace soils derived from marine or residual material
6. Lowland soils derived from residual material
7. Organic soils (peat and muck)

Eastern Washington Division

Because irrigation has a distinct influence on productivity and on certain other characteristics of arid soils, it was considered advisable to group the irrigated soils separately. The results obtained on irrigated soils will be presented by separate districts because of distinct differences in the soils.

The non-irrigated soils of eastern Washington have been classified in two main groups. The first group consists of the semi-arid wheat lands which are found in what may be called the Palouse formation, and the second group comprises the various terrace and lowland soils of northeastern Washington. Due to the fact that a comparatively small number of experiments were conducted on the soils in this area, no further subdivision seemed justified at this time. The grouping of the soils of eastern Washington that will be used in the discussion is as follows:

1. Irrigated terrace soils derived from alluvial material
2. Terrace and lowland soils derived from glacial or residual material
3. Soils of the Palouse formation

It is fully appreciated that the proposed grouping of the soils of Washington is one of expediency limited only by the lack of more definite information, such as is obtained from a detailed soil survey. If, however, it is realized that the subject of soil fertility is intimately associated with the nature of the soil and that soils derived from similar parent material and developed under similar processes of soil formation have many characteristics in common, it becomes obvious that the use of this grouping as a basis for the discussion of the results obtained from the fertilizer experiments is justifiable and appropriate, though arbitrary.

GENERAL DISCUSSION OF RESULTS

Because of the evident lack of information regarding the fertility of soils of the state in general and of western Washington in particular, one of the chief objects of the cooperative fertilizer plot project was to ascertain the fertility requirements of these various soils. To attain this object, it was necessary to establish fertilizer plots on as many different soils as possible and to make the applications of fertilizers sufficiently large to overcome any of the usual deficiencies of plant nutrients in the soils. Therefore, the rates of application noted in Figures 1 to 7, inclusive, were designed in an attempt to supply these deficiencies and not with the intention of establishing suitable ratios of plant food elements in the fertilizers or economical rates of application.

During the six years in which the project has been in progress, sufficient fertilizers for a total of 397 experiments have been shipped to the cooperators. As might well be expected from this type of cooperative projects, complete data have not been obtained for all of the experiments. Various unavoidable conditions, such as drought, frost, or failure on the part of the cooperating farmers to advise their supervisors of the time the crop was being harvested must be taken into consideration. Reliable yields have been obtained, however, from approximately 259 experiments, and all of these have been included in this report. This number does not include the six pasture fertilizer trials established by the western representative of the Agricultural and Scientific Bureau of the N. V. Potash Export My., Inc. The results of this experiment are discussed in a separate section.

It will be noted that the number of experimental plots in the different groups of soils varies considerably, although a serious effort has been made throughout to keep the distribution as uniform as possible. The reason that some soil groups appear to be better represented than others can be explained partly on the basis of the agricultural importance of the soils and partly on the basis of the degree of enthusiasm manifested by the cooperators in their respective localities. A comprehensive idea of the distribution of the fertilizer experiments can be gained from Figure 8 which shows the approximate location of each experiment.

A careful study of the results of the fertilizer trials as a whole reveals that there are extreme variations in the natural productivity of the soils. In certain soils the natural productivity is so low that even the addition of relatively large quantities of complete fertilizers fails to effect the production of normal yields, whereas in others it is so high that only slight increases in yields can be obtained with applications of fertilizers. The majority of soils, however, fall between these extremes, and satisfactory increases in yields can be obtained when

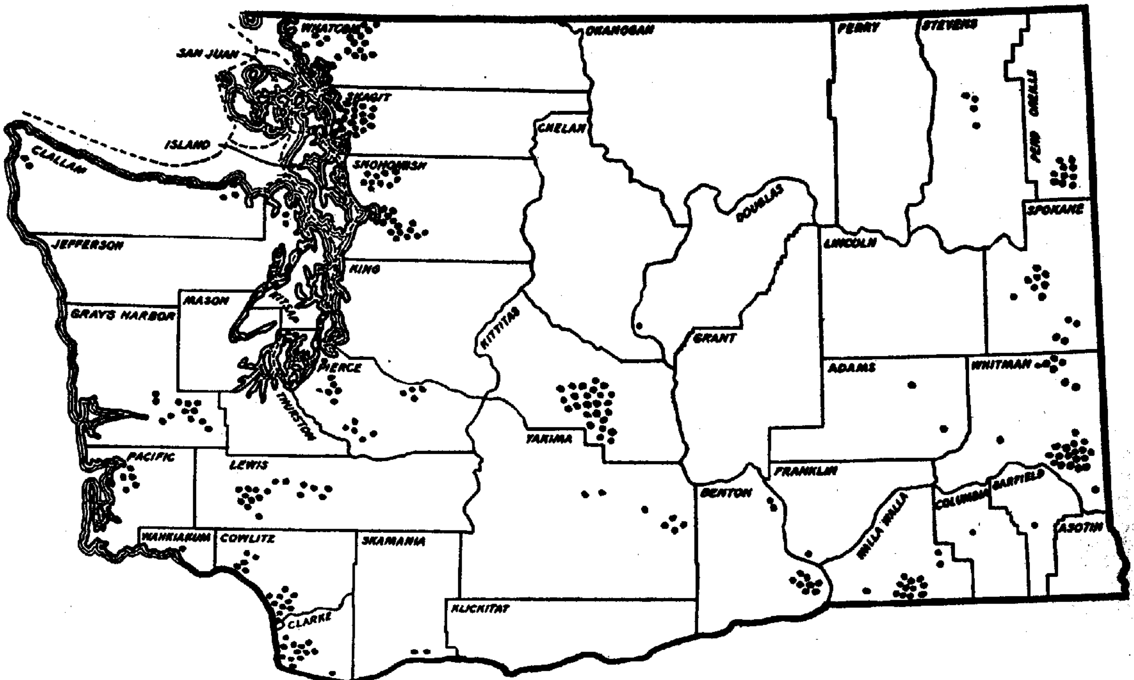


Fig. 8. Approximate Location of the Experimental Plots of the Cooperative Fertilizer project. The locations are indicated by dots.

certain deficiencies in plant nutrients are corrected by means of fertilizers. These facts are brought out distinctly when the yields of all the forage crops on the Check, N, NP, and NPK plots of the fertilizer experiments on western Washington soils, a total of 80 trials, are compiled and classified in three groups. Those from the soils of low natural productivity have been placed in one group, those from the soils of medium natural productivity in a second group, and those from the soils of high natural productivity in a third group. Since the crops grown for the majority of the experiments are representative of general farm crops, the yields for each group have been averaged to serve as a basis for the interpretation of the response of the crops in general to fertilizers. The results are graphically illustrated in Figure 9.

It is clearly demonstrated that there is a possible maximum production for any given soil beyond which any attempt to increase production further by the use of fertilizers is not economically sound. For the low yielding soils this is less than one ton of forage per acre,

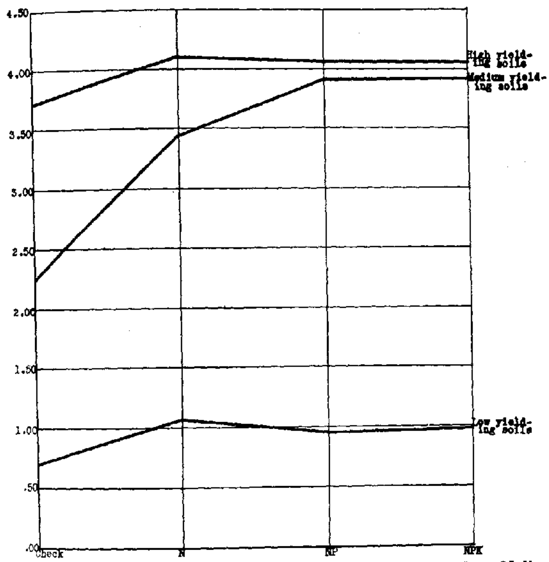


Fig. 9. Average Yields in Tons per Acre of Forage Crops on Soils Low, Medium, and High in Natural Productivity.

while for the high yielding soils it is about four tons of forage per acre. This point is important and must receive careful consideration in connection with the economical utilization of fertilizers. Fertilizers represent a cash outlay, and therefore should be used only where they will bring cash returns either by way of direct increases in yields or by way of building up the soil fertility for future crops. The question may be raised of the advisability of ever using these low yielding soils for the production of general farm crops.

A careful consideration of the results as a whole also reveals that certain crops appear to respond better to fertilizer treatments than others. The difference in response is more apparent than real as it is known that all farm crops, irrespective of their individual characteristics, require fundamentally the same elements of plant food. Consequently, the difference in requirements is one of degree and not of kind. The chief reasons that better responses from fertilizer treatments were obtained with certain crops than with others are the environmental conditions, such as plant diseases or lack of sufficient moisture during a part of the growing season. Thus, the matter of plant food deficiencies is primarily and distinctly a problem that is associated with the soil.

EXPERIMENTAL RESULTS

The results from each group of soils under the two main divisions are presented separately, and will be interpreted as much as possible on the basis of average yields grouped in relation to the natural productivity of the soils as discussed in the foregoing section and illustrated in Figure 9. Although certain definite general trends are indicated, caution must be exercised in reaching final conclusions for particular soils because in many cases more experimental data are required, as will be pointed out in the following sections.

Soil Groups in Western Washington

1. Upland Soils Derived from Glacial Material

These soils have been derived directly from the weathering of glacial drift, and occupy the rolling uplands and the lower foothills of the mountainous areas extending from the Canadian boundary on the north to approximately the southern boundary lines of Thurston and Pierce counties. They are found extensively in Whatcom, San Juan, Island, Skagit, Snohomish, King, Kitsap, Clallam, Jefferson, Mason, Pierce, and Thurston counties. Although the parent material from which the soils have been formed and the mode of formation are similar, the texture, or the size of particles, varies from sandy loams with gravelly, excessively drained subsoils to silty and silty clay loams with heavy, compact, and poorly drained subsoils. Therefore, a con-

Table 1. Results of Fertilizer Treatments of Upland Soils Derived from Glacial Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED															
								CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
D106	A.W.Folland Port Angeles	A.R.Hunt Sequim	Clallam	Clallam Gr.F.S.L.	Vetch	1931	Tons	1.39	2.06	1.71	1.90	1.95	1.95										
C105	"	O.J.Ford Forks	"	not classified	Oats	1930	Bushels	71.00	108.00	87.00	101.00	39.00											
D105	"	"	"	"	Hay	1931	Tons	1.11	1.87	2.92	2.79	0.88	0.77	1.83	2.92	3.49	4.48	2.52					
A14	E.W.Blaisdell Eatonville	Peterson	Pierce	Everett Gr.L.S.	Potatoes	1928	"	10.24				12.90	12.09	8.44				10.81	7.98	10.78			9.48
A15	"	Johnson	"	Everett Gr.S.L.	"	1928	"	7.21				6.34	7.21	6.23				8.03	7.08	5.94			7.48
B11	"	E.W.Blaisdell Eatonville	"	Everett Gr.L.S.	"	1929	"	6.53	5.99	6.81	7.62	5.99	4.90	10.89	8.98	7.62	8.17	5.45	5.45	7.62	8.17	8.71	8.17
B1	B.D.Boyer Arlington	E. Holm R.2 Arlington	Snohomish	Everett Gr.S.L.	"	1929	"	7.71	8.02	8.59	10.77	8.89	6.20	7.08	6.99	6.96	9.20	8.89	6.47	9.92	11.62	10.74	6.14
C1	"	"	"	"	Oats and Vetch	1930	"	2.57	4.24	5.45	5.45	3.18	2.27	3.33	4.99	5.45	5.75	4.08	4.08	3.03	5.14	4.24	5.49
D1	"	"	"	"	Clover 1 cutting	1931	"	2.03	2.02	2.56	2.51	1.15	1.15	1.47	2.23	2.04	2.88	2.16	1.73	1.39	2.08	2.57	2.69
A 3	"	P.Ness Edgecomb	"	"	Alfalfa 1 cutting	1928	"	3.67				3.59	3.34	3.70				3.54	3.83	3.88			3.89
A2	"	J. Carlson English	"	"	Clover 1 cutting	1928	"	2.50				5.41	3.71	3.42				4.61	3.36	3.36			3.68
B39	C.B.McColley Vaughn	C.B.McColley Vaughn	Pierce	"	Oats	1929	Bushels	18.00	68.00	52.00	36.00	18.00	25.00		38.00	78.00	47.00	21.00	34.00	21.00	45.00	48.00	16.00
C57	"	"	"	"	Oats and Vetch	1930	Tons	0.87	1.94	1.42	1.41	0.49	0.58		1.11	1.44	1.72	1.04	1.47	0.89	1.68	1.54	1.33
C142	A.Z.Smith Everett	Logan Bros. East Stanwood	Snohomish	"	Clover 1 cutting	1930	"	2.24	2.36	2.18	2.54	2.27											
D138	"	"	"	"	"	1931	"	2.71	4.26	3.48	4.26	4.65	3.10	3.16	2.71	3.87	4.26	5.42	2.13				
B117	[illegible]W.Ternahan Port Townsend	C.Thompson Port Townsend	Jefferson	Everett S.L.	Potatoes	1929	"	2.07	2.50	3.05	3.27	3.59	3.67	2.67			2.61	3.21		2.67	2.63	2.89	2.46
C114	"	Wm. Bishop Chimacum	"	"	Oats and Vetch	1930	"	2.87	3.55	2.52	3.48	3.08											
Y5	[illegible]Windus Mt.Vernon	Astel	Skagit	Everett Gr.S.L.	Wheat and Peas	1927	"	0.42				0.94	0.84	0.76				0.93	0.74	0.74			0.51
B135	[illegible].Richardson [illegible]oma	C.J.Lawson R.2 Puyallup	Pierce	Orting Loam	Corn for Silage	1929	"	9.34	11.79	11.19	11.52	10.40											
C136	"	"	"	"	Oats and Vetch	1930	"	3.81	5.94	7.29	8.44	3.64											
C6	[illegible]earson [illegible]lington	J.T.Dickensen R.2 Mt.Vernon	Skagit	Whatcom Si.L.	Wheat	1930	Bushels	45.00	46.00	40.00	44.00	44.00		39.00									

S—sand; [illegible]—silt; C—clay; L—loam; Gr—gravelly; F—fine.

siderable variation in productivity may be expected. Twenty-one experiments were conducted on the soils of this group and the results are presented in Table 1.

There are some interesting points in these results. One is that the response of potatoes to fertilizers in the five fertilizer trials conducted on these soils was not as good as might be expected from the amounts of fertilizers applied. The average yield of the check plots was 6.7 tons per acre, and that of the plots treated with complete fertilizers was 7.2 tons per acre, an increase of less than one ton from the application of a combination of 300 pounds of nitrate of soda, 600 pounds of superphosphate, and 200 pounds of sulfate of potash. Probably one of the reasons for this lack of response is the prevalence of potato diseases commonly found in western Washington, and another reason, in certain instances at least, may have been the lack of sufficient moisture during a part of the growing season.

The second interesting feature in these results is the response of forage crops, including the grasses cut for pasture and for hay, the cereals cut for hay, and the legume hays. When the soils are segregated according to the grouping proposed in the section on general discussion of results, it is found that two of the experiments were on soils that are naturally low in productivity, giving yields that are within the range indicated by the lower curve in Figure 9, page 17. These low yields are generally obtained on the excessively drained, gravelly soils where the use of fertilizers for general farm crops is ordinarily not an economical practice. Good responses from fertilizers were obtained, however, on the eight experiments on soils of medium natural productivity. The average yield of the forage crops was 2.3 tons per acre on the check plots and 3.9 tons per acre on the plots receiving complete fertilizers. The greatest response was obtained with nitrogen, and some additional increases in yield were obtained with phosphate, and with phosphate and potash in combination with nitrogen fertilizers. The results on this group of soils are very similar to those shown by the second curve in Figure 9, suggesting that the judicial application of fertilizers for general farm crops on these soils is sound farm practice. More experimental work is needed, however, to verify the trend thus far shown.

2. Terrace Soils Derived from Glacial Material

The terrace soils occupy comparatively level to undulating flood plains of glacial streams or lakes, and are derived principally from more or less stratified deposits of sand and gravel laid down over broad valleys by the water of glacial floods, or of coarse gravel with little or no fine material left by the swift waters of sub-glacial streams, or deposited uniformly over the basin of ice-bound glacial lakes. The sandy texture of both surface and subsoil of the former results in

thorough to excessive drainage, so that the crops frequently suffer damage from lack of sufficient moisture during the growing season. These soils occur in rather extensive areas, mainly in the western part of Whatcom county but also to some extent in Snohomish and Skagit counties. The coarse, gravelly types are found principally in what is known as the Tacoma Prairie in Pierce, Thurston, and Mason counties. A few small isolated areas occur also in Grays Harbor and Clallam counties where in many cases the coarse gravel has been covered by shallow layers of fine material washed down from the adjacent uplands. The excessively drained, coarse, gravelly types of soil usually are low in agricultural value.

The results of the 11 fertilizer trials conducted on terrace soils derived from glacial material are presented in Table 2. The yields of all except two of the trials with forage crops fall within those represented by the lower curve in Figure 9.

Although the number of experiments is comparatively small, there are definite indications that many of these soils are not sufficiently responsive to fertilizer treatments to justify the practice as a paying proposition for general farm crops. This is especially true of the coarse gravelly soils where a deficiency in moisture during the growing season is a usual occurrence and where only a limited number of certain special crops can be grown successfully. Before any definite conclusions can be reached, however, the experiments should be continued on a larger number of the sandy soils of this group which seem to offer better prospects for satisfactory results.

3. Lowland Soils Derived from Glacial Material

The lowland soils are alluvial in nature and occupy the stream valleys and the broad delta lands at the mouth of some of the larger rivers. They have been formed principally of glacial material carried down by rivers and deposited over valleys at times of flood or in shallow bays at the mouth of rivers. Some of the soils in this group occupy shallow basins which were formerly small lakes or ponds that have since been filled in with fine glacial material washed down from the surrounding uplands. These soils are usually well supplied with organic matter but often require artificial drainage. When thoroughly drained by natural or artificial drainage the lowland soils are medium to high in natural productivity, and are classed among the best agricultural soils in the Puget Sound region. The soils, although fairly uniform in texture, vary from sandy loams to silt loams and silty clays; therefore, they may be expected to differ considerably in productivity. Extensive, important agricultural areas of lowland soils are located in Whatcom, San Juan, Skagit, Island, Snohomish, King, Kitsap, Mason, Pierce, and Thurston counties, and a few small areas are scattered in the southwestern part of Clallam and in the central part of

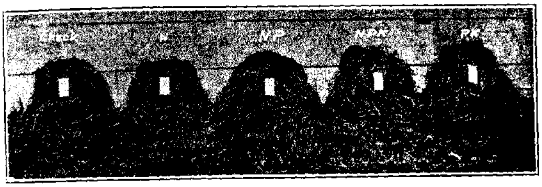
Table 2. Results of Fertilizer Treaments on Terrace Soils Derived from Glacial Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED															
								CHECK	N	NP	NPK	PK	.P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
X 1	S. D. Boyer Arlington	Anderson	Snohomish	Lynden S. L.	Potatoes	1926	Tons	3.03				4.52	3.25	3.82				3.96	4.32	3.57			3.83
D 2	S. D. Boyer Arlington	R. Thompson R1 Arlington	"	"	Alfalfa N.S* 2nd cutting	1931	"	0.08	0.12	0.15	0.18	0.18	0.09	0.28	0.23	0.29	0.34	0.25	0.11				
C 153	H.B. Carroll Bellingham	L. C. Boggs R2 Bellingham	Whatcom	"	Alfalfa N.S.* 1st cutting	1930	"	0.45	0.38	0.44	0.53	0.39		0.38	0.47	0.43	0.49	0.38					
D 137	"	"	"	"	Alfalfa 5th cutting	1931	"	0.28	0.42	0.54	0.49	0.51		0.29	0.41	0.53	0.51	0.42					
D 27	F. Rockey Lynden	G. Brenner Lynden	"	"	Grass Hay	1931	"	0.97	2.38	1.16	1.74	1.28	1.94	1.07	2.71	1.60	1.07	1.55	1.26				
A 19	O. O. Baker Elma	School Farm Elma	Grays Harbor	Spanaway Gr. S. L.	Alfalfa	1928	"	0.74				0.67	1.08	2.45				2.40	2.09	0.98			2.51
X 12	"	"	"	"	Corn for Silage	1926	"	1.79				2.42	2.10	1.61				2.20	2.08	1.95			1.75
B 12	"	"	"	"	Grass Hay	1929	"	0.25	0.27	0.77	0.90	0.32	0.39	0.15	0.27	0.62	0.64	0.31	0.24	0.18	0.35	0.27	0.13
C22	H. Olsen Elma	"	"	"	"	1930	"	1.51	2.12	2.42	3.05	1.21	1.21	2.43	2.72	2.67	3.16	1.82	1.82	1.81	2.42	2.42	1.82
B 35	H.E. Loomis Roy	E. W. Castle Roy	Pierce	"	Oats	1929	Bushels	15.00	25.00	26.00	31.00	30.00	17.00	17.00	18.00	36.00	26.00	13.00	13.00	17.00	19.00	15.00	4.00
D 39	"	J.F McAlexander Roy	"	Spanaway F. S. L.	Oats and Hay	1931	Tons	2.19	8.29	3.43	3.22	2.04	2.31										

* N.S.—New Seeding

Lewis counties. Because of their great agricultural importance, 50 fertilizer experiments have been established on these soils. The results are presented in Table 3.

By segregating the soils according to their natural productivity as indicated by the yields of forage crops, it is shown that there was only one low yielding soil in the entire group. In this particular case the low yield happened to be caused by severe insect injury to the crop, and so there were actually no low yielding soils. In sharp contrast with this interesting fact, the yields of five experiments fall within the range of those obtained on high yielding soils, as indicated by the third or upper curve in Figure 9, clearly demonstrating that the natural productivity of these five soils is so high that any attempt to increase the yield of crops commonly grown in general farming would probably not result in profitable returns. The large majority of the soils on which forage crops were grown, 24 in all, appear to be of medium natural productivity as shown by the excellent crop response to fertilizers. The average acre yield of forage on the check plots was 2.6 tons, that on the nitrogen plot was 3.8 tons, that on the nitrogen and phosphate plots was 4.53 tons, and that on the plots receiving complete fertilizers was 4.32 tons, which is a slight decrease over that of the nitrogen and phosphate plots. The reason for this decrease is not entirely clear.



Results on a Soil of High Natural Productivity where Yields Are Excellent without Fertilizers.

The effect of fertilizers on grass hay on a lowland soil derived from glacial material. The yield of hay on the untreated plot was 3.09 tons, and the highest yield in this experiment was 4.10 tons per acre. The plot treated with a combination of nitrogen and phosphate fertilizers gave the highest yield in this case.

It will be noted that the yields are somewhat greater than those represented by the central curve in Figure 9, but the results are comparable with the exception that a markedly better response was obtained from the plots receiving phosphate in combination with nitrogen. Although the increases in yield resulting from the addition of nitrogen alone were very significant, additional increases were obtained with a combination of nitrogen and phosphate fertilizers, indicating

Table 3. Results of Fertilizer Treatments on Lowland Soils Derived from Glacial Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED															
								CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
D28	O.Loreen Ferndale	P. Munson Ferndale	Whatcom	Bellingham Si. L.	Oats Hay	1931	Tons	3.06	5.18	4.96	5.89	2.91											
C36	M. Windus Mt. Vernon	A. Mistonen R.4 Mt. Vernon	Skagit	"	Pasture 1 cutting	1930	"	0.68	1.60	1.66	1.92	1.40											
D33	"	"	"	"	"	1931	"	0.80	2.08	2.56	2.08	0.80											
A9	A. Kulin Buckley		Pierce	Buckley loam	Oat Hay	1928	"	1.40	2.23	3.53	3.24	1.32	1.61	1.74	2.09	2.30	2.79	1.40	1.67	1.40	2.44	2.79	1.44
C5	H.I.Magladry Buckley	J. C. Ames Buckley	"	"	Potatoes	1930	"	11.57	10.77	12.10	14.28	14.52											
D6	"	"	"	"	Oat Hay	1931	"	3.56	5.05	4.98	4.66	4.59											
B5	"	F. D. Phillips Buckley	"	"	Potatoes	1929	"	6.78	7.74	4.64	4.36	6.29	5.81	5.34	5.08	4.11	5.08	4.84	4.56	6.29	8.71	8.71	7.3[illegible]
C58	F. D. Rockey Lynden	J. Bierlink Lynden	Whatcom	Custer Si. L.	Pasture 3 cuttings	1930	"	5.35	4.46	8.40	6.35	4.80		4.16	6.67	5.94	8.88	3.97					
D56	"	"	"	"	Pasture 2 cuttings	1931	"	1.07	1.97	3.94	3.67	2.10	2.31	1.89	2.72	3.56	5.14	2.04	1.89				
C50	H. Alexander Sequim	H. F. Hitt Sequim	Clallam	Dungness Si. L.	Alfalfa 1 cutting	1930	"	2.45	2.43	3.61	3.66	3.90											
A1	S. D. Boyer Arlington	C. Rolling Cicero	Snohomish	Puget Si. L.	Potatoes	1928	"	6.15	6.55	6.97	6.97	6.55	5.86	7.30	6.53	6.57	7.50	7.21	7.11	7.94	6.24	6.59	7.42
C67	S. L. Brown Woodland	L. C. Peek Woodland	Cowlitz	Puget Si.	Alfalfa 3 cuttings	1930	"	5.28	6.22	8.88	9.12	7.10											
D40	"	"	"	"	Alfalfa 2 cuttings	1931	"	3.40	5.11	5.65	5.71	8.13	4.20	3.10	3.87	3.25	5.11	5.65	4.02				
A11	F. C. Dickey Deming	High School Deming	Whatcom	"	Potatoes	1928	"	7.80	8.90	5.50	5.80	6.00	6.00	11.80	14.30	9.70	9.80	5.90	5.60	6.30	9.40	9.80	14.60
B10	"	"	"	Puget Si. L.	"	1929	"	6.97	6.66	6.25	7.57	8.11	4.19	4.06	5.45	4.30	8.68	8.86	4.52	5.99	5.66	6.38	8.3[illegible]
G17	"	"	"	"	Sugar beets	1930	"	10.45	18.45	10.89	15.19	13.18	15.87	6.53	5.28	11.38	25.26	11.54	6.70	15.65	13.29	10.85	9.81
D17	"	"	"	"	"	1931	"	18.40	17.44	23.63	23.52	21.24	22.54	11.11	17.21	18.79	25.75	23.96	12.35	16.55	19.00	22.49	17.37
A13	"	D. Douglass Acme	"	"	Potatoes	1928	"	11.40				17.70	14.70	9.00				13.00	8.70	7.90			11.40
C18	"	C. Henderson R.2 Everson	"	"	Alfalfa 2 cuttings	1930	"	5.48	6.76	6.97	7.26	9.10	6.38	5.90	7.65	9.10	7.74	7.65	7.74	6.58	7.36	7.3[illegible]	[illegible]
B58	L. D. Fairbairn Sumas	J.A.Lockbaum Sumas	"	"	Barley	1929	Bushels	25.00	55.00	55.00	51.00	29.00	31.00	54.00	37.00	58.00	56.00	29.00	22.00	44.00	51.00	47.00	48.00
C58	"	"	"	"	Pasture 3 cuttings	1930	Tons	1.50	4.13	5.08	3.27	2.22		1.96	3.58	3.92	3.21	1.79					
D43	"	"	"	"	"	1931	"	3.58	4.61	6.59	7.04	2.99		4.02	3.79	5.01	6.41	4.70					
C49	A. D. Foster Sedro Woolley	L.Christoferson Sedro Woolley	Skagit	Puget Si. C.	Grass hay 2nd cutting	1930	"	1.67	1.80	1.58	1.38	2.64		1.66	1.43	1.84	1.55	2.09					
D40	"	J. Parker Sedro Woolley	"	Puget F. S. L.	Oats and Vetch	1931	"	2.12	2.45	3.57	4.16	2.83	3.16	2.56	3.34	2.67	3.88	2.58	2.30				
C206	W. S. Grunder Puyallup	J. Brandli R.1 So. Prairie	Pierce	Puget Si. L.	Clover 1 cutting	1930	"	3.01	2.25	3.94	3.54	3.38											
C207	"	A.W. Langdon Sumner	"	Puget S. L.	Wheat Hay	1930	"	3.58	4.16	4.61	4.98	4.64											

Table 3 (Cont.) Results of Fertilizer Treatments on Lowland Soils Derived from Glacial Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED															
								CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
D127	A.M.Richardson Tacoma	A.W.Langdon Sumner	Pierce	Puget C. L.	Grass Hay	1931	Tons	3.09	2.95	4.10	3.83	2.88											
B37	B. Hardin Sultan	R. H. Odlin Sultan	Snohomish	Puget Si. L.	Potatoes	1929	"	5.08	5.81	7.01	8.47	7.08	6.05	5.81	7.50	8.23	8.83	7.62	5.14	5.38	5.87	[illegible]	7.88
C53	"	"	"	"	Oat Hay	1930	"	0.91	3.63	4.84	3.01	1.21	1.21	1.21	2.12	3.01	3.63	1.82	1.82	0.91	4.24	2.42	1.82
C54	"	S. N. Smith R.1 Sultan	"	Puget S. L.	"	1930	"	1.21	1.82	3.63	3.63	2.42											
C52	E. R. Hawley Snohomish	E. Hoem R. 2 Snohomish	Snohomish	Puget Si. L.	Oat and Pea Hay	1930	"	2.80	2.80	3.74	4.30	3.83											
Y4	C. Lybacker Monroe	Sohum R.2 Monroe	"	Puget S. L.	Mangels	1927	"	4.92	7.00	7.80	8.16	10.45	5.75	4.78	6.28	3.67	5.53	5.40	4.73	7.32	7.96	6.81	7.45
A22	"	"	"	Puget Si. L.	Potatoes	1928	"	8.58				8.32	7.36	8.23				7.94	8.03	10.28			8.38
A21	"	G.E. Taylor R.2 Monroe	"	"	"	1928	"	6.05	6.00			5.80	6.10	6.90				7.90	7.30	5.30			7.70
B24	"	F. Bosch Monroe	"	Puget Si. C.	Oat Hay	1929	"	3.26	4.84	3.75	4.11	3.26	3.15	2.90	4.11	3.87	4.48	2.90	2.78	3.05	4.11	4.72	3.36
C33	"	G. E. Taylor R.2 Monroe	"	"	Oats and Peas	1930	"	4.36	5.93	3.82	3.61	5.35											
B4	M. H. Pearson Burlington	N. Tennyson Burlington	Skagit	"	Oats	1929	Bushels	104.00	143.0	90.00	126.00	104.00	95.00	129.00	134.00	117.00	110.00	114.00	105.00	100.00	121.00	112.00	100.00
C7	"	D. Razor R. 1 Bow	"	"	Pea Hay	1930	Tons	5.68	4.85	4.16	4.36	2.86											
D7	"	C. Schroeder R.D. Bow	"	"	Pasture 3 cuttings	1931	"	3.27	3.19	3.58	3.24	3.10											
D30	G. E. Treil Monroe	C. E. Taylor R.2 Monroe	Snohomish	Puget Si. L.	Oats and Peas	1931	"	0.72	0.91	1.01	1.06	0.84	0.64										
Y7	M. Windus Mt. Vernon		Skagit	Puget S. L.	Alfalfa 1 cutting	1927	"	1.94				2.30	1.80	2.03				2.35	1.66	2.74			2.31
A25	"	E. Callahan Fredonia	"	Puget Si. L.	Potatoes	1928	"	10.65				9.92	6.29	6.29				5.81	5.69	11.37			8.88
C37	"	W. Johnson R.1 Mt.Vernon	"	Puget Si. C.	Pasture 3 cuttings	1930	"	3.44	5.60	6.32	5.04	4.56											
D34	"	"	"	"	Pasture 2nd cutting	1931	"	0.53	0.99	0.98	0.81	0.76											
D71	"	E. S. Sargent R.1 Mt.Vernon	"	Puget Si. L.	Pasture 1 cutting	1931	"	1.23	1.62	1.70	1.97	1.49	1.76	1.59	1.66	1.55	1.67	1.65	1.35				
D72	"	W. Schroeder R.1 Mt.Vernon	"	"	"	1931	"	1.58	1.38	1.51	1.66	1.66	1.57	1.86	1.27	1.43	1.60	1.62	1.65				
D74	"	A. Olson R.3 Mt.Vernon	"	Puget Si. C.	Pasture 2 cuttings	1931	"	3.66	4.51	5.69	5.21	5.00	4.76										
D75	"	J. Wylie R.3 Mt.Vernon	"	"	Grass Hay	1931	"	2.71	2.58	3.35	4.15	3.10	2.51	2.90	2.85	4.06	2.58	1.94	2.15				
B25	L.E. Duncan Mossyrock	L. Birley Mossyrock	Lewis	Not Classified	Oats	1929	Bushels	101.00	135.00	132.0	134.0	113.00	149.00	113.00	135.00	143.00	162.00	128.00	134.00	130.00	111.00	164.00	129.00
C34	W. M. Burt Mossyrock	"	"	"	"	1930	"	76.00	76.00	119.00	67.00	53.00	84.00	47.00	65.00	67.00	88.00	92.00	84.00	55.00	70.00	48.00	83.00

that many of these lowland soils are beginning to be deficient in available phosphorus as well as in available nitrogen and that the use of moderate amounts of nitrogen and phosphate fertilizers for general farm crops is sound practice.

The results of the 10 experiments with potatoes were not very satisfactory. The average yield of the check plots was 7.4 tons and that on the plots treated with complete fertilizers was 7.9 tons, or an increase of less than a ton per acre as a result of a moderate but reasonably large application of a complete fertilizer. Although the well-drained lowland soils should be able to produce markedly better yields of potatoes than the upland soils derived from glacial material, the average yield was only slightly greater, showing that most probably the potato diseases materially affected the results.

4. Upland Soils Derived from Residual Material

The upland soils derived from residual material are uniformly of finer texture than those derived from glacial material. They are principally clay loams and silty clay loams, light brown to reddish in color, and they occupy the hilly upland districts of southwestern Washington. These soils are derived directly from the weathering of the underlying rocks which consist mainly of basalt but, in places, of andesitic or related rocks. On account of the rough topography many of the soils are not well suited for general agriculture. The drainage is usually good and because of their fine texture the soils are retentive of moisture. Some of the less hilly, important agricultural areas are found near the southern boundaries of Pierce and Thurston counties and in several places in Grays Harbor, Pacific, Lewis, Wahkiakum, Cowlitz, Clark, and Skamania counties. The results of the 16 fertilizer trials established on these soils are reported in Table 4.

In addition to the usual experiments with cereals, forage crops, and potatoes, two fertilizer trials with strawberries are reported, and it will be noted that the results are not outstanding. Strawberries have not proved a very suitable crop for this sort of experiment because of the difficulties in obtaining accurate yields and also because weather conditions, such as late frosts during blossoming time and rain at picking time, frequently interfere with the results. The yields of the forage crops, however, when classified according to the natural productivity of the soils, show that of a total of eight trials only one falls within the low yielding group of soils, whereas the remaining seven show clearly that general farm crops respond satisfactorily to fertilizer treatments. The application of nitrogen fertilizers has given the greatest increases in yield, but phosphate or phosphate and potash in combination with nitrogen have given additional increases. Thus far it seems that nitrogen has given the best returns, but because of the

Table 4. Results of Fertilizer Treatments on Upland Soils Derived from Residual Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED															
								CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
X10	G. O. Baker Elma	O. Jarvis Malone	Grays Harbor	Melbourne Si. C. L.	Strawberries	1926	Tons	0.93				1.11	1.00	1.60				1.24	1.13	1.13			1.87
C29	E. Cooke Menlo	A. Rothlin Holcomb	Pacific	"	Oat Hay	1930	"	2.42	6.66	4.84	6.05	4.24	2.72	3.03	5.14	4.54	4.84	8.48	3.63	4.24	5.45	4.24	3.63
O9	J.L. Helm Centralia	O. Lewis Centralia	Lewis	"	Oats	1930	Bushels	6.00	62.00	79.00	58.00	24.00											
D9	"	"	"	"	Oats and Vetch	1931	Tons	1.39	3.26	4.40	3.58	1.78	1.26										
D113	L.S.Sorensen Montesano	L. Holdereed Oakville	Grays Harbor	"	Strawberries	1931	"	1.64	1.43	1.58	1.66	1.40	1.66										
C130	B.J.Valentine Menlo	A. Kraus R.1 Raymond	Pacific	"	Potatoes	1930	"	0.23	0.49	0.57	0.63	0.67											
C108	C.S.Anderson Kelso	C. King Silverlake	Cowlitz	Olympic C. L.	Pasture 2 cuttings	1930	"	1.36	3.59	4.24	4.71	2.15											
D109	"	"	"	"	Pasture 2nd cutting	1931	"	0.60	0.88	0.82	0.67	1.10	0.92	0.26	0.62	0.43	0.32	0.44					
C68	B. L. Brown Woodland	W.F.Christensen Star R. Woodland	"	Olympic Si. C. L.	Pasture 2 cuttings	1930	"	1.49	1.73	1.60	2.80	1.50		1.51	2.06	2.27							
D50	"	"	"	"	Pasture 2nd Cutting	1931	"	1.06	1.38	2.07	2.10	1.09											
C65	"	H. Basso Woodland	"	"	Strawberries	1930	"	1.12	0.90	1.01	1.20	1.50											
D51	"	"	"	"	"	1931	"	1.72	1.36	1.60	1.86	2.66	1.64										
D52	"	W. Sherman Woodland	"	"	Alfalfa	1931	"	1.94	3.79	3.40	4.18	2.56											
D150	W. S. Gillard Stevenson	Berge Bros. Home Valley	Skamania	"	Potatoes	1931	"	3.60	3.05	4.20	5.35	5.80	5.80										
D12	H. S. Porter Chehalis	Burns Bros. R.4 Chehalis	Lewis	Olympic C. L.	Oats and Vetch	1931	"	0.97	3.87	4.36	4.36	1.94	1.69										
C141	W. S. Gillard Stevenson	Berge Bros. Home Valley	Skamania	Underwood Si. L.	Potatoes	1930	"	7.00	1015	8.25	9.00	8.25											

relatively small number of experiments on these soils it will be necessary to continue the experiments on a larger number of soils before definite conclusions can be drawn.

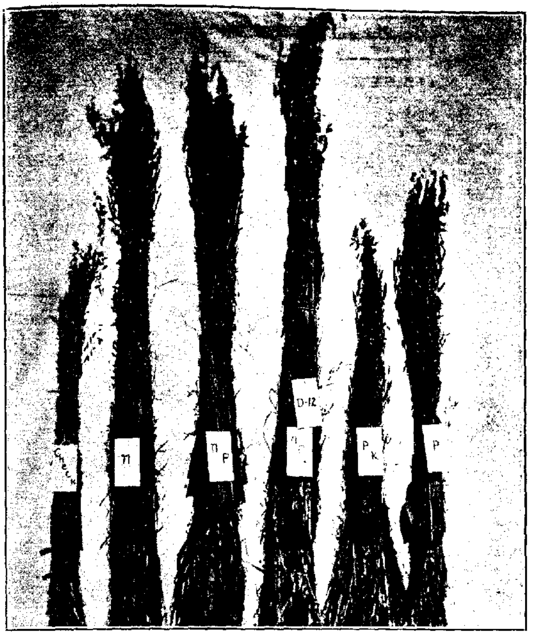
5. Terrace Soils Derived from Marine or Residual Material

The terrace soils represent the earlier flood plains of the streams. Some of these terraces are very old, and the material originally deposited has weathered to a considerable depth leaving no indication of stratification in the soil profile. The greater proportion of the level to gently rolling terrace lands formed more recently along the course of the larger streams are underlaid by stratified deposits of sand and gravel covered to an average depth of three to 10 feet by finer deposits of sand, silt, and clay. In some localities a considerable quantity of water-worn gravel occurs mixed with the finer surface soil. The material from which these soils are derived is residual or marine in origin, and has been deposited during the time when these stream valleys and basins served as drainage channels or flood plains. The terrace soils are usually well to excessively drained, but with the exception of the coarser gravelly types are retentive of moisture and well suited to general agriculture. Important areas of these soils are located in Grays Harbor, Pacific, Lewis, Wahkiakum, Cowlitz, Clark, and Skamania counties. Results of the 21 fertilizer experiments conducted on these soils are recorded in Table 5.

The data presented show that of the 16 trials with forage crops the yields of three are within the range represented by the lower curve in Figure 9. These data indicate that these soils are naturally low yielding and are not improved materially by the use of fertilizers. The average yields of the other 13 experiments show that forage crops responded very well to the fertilizer treatments. Evidently the soils in these cases may be classed as medium yielding. The results seem to signify that the judicial use of fertilizers for general farm crops is good practice. Again the greatest average increase in yield was obtained with nitrogen, but phosphate and phosphate and potash fertilizers in combination with nitrogen gave additional increases.

It will be noted that the results of the two experiments with potatoes are not indicative of what fertilizers can do in the way of increasing yield. The principal reason for this condition is probably the same as that given in connection with the soils derived from glacial material, largely a disease factor.

There are some indications in the data presented in Table 5 that legumes responded to lime treatments. The number of occurrences, however, is not sufficiently large to allow any definite conclusion at this time.



Results on a Soil of Medium Natural Productivity where the Use of the Proper Fertilizer Is Good Practice.

The effect of fertilizer treatments on oats and vetch on an upland soil derived from residual material. The untreated plot yielded at the rate of 0.97 tons per acre, the N plot at the rate of 3.87 tons per acre, the NP plot at the rate of 4.36 tons per acre, and the NPK plot at the rate of 4.36 tons per acre.

6. Lowland Soils Derived from Residual Material.

The lowland soils occupy the flood plains of the principal rivers and in some cases shallow basins which were formerly small lakes or ponds. They have been formed from residual material carried down by the rivers and deposited over the valleys and in the basins. These alluvial deposits, although derived from non-glacial material, vary to a greater extent than those previously described as being derived from glacial material. The soils along the Columbia river, for instance, are

Table 5. Results of Fertilizer Treatments on Terrace Soils Derived from Marine or Residual Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED															
								CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
D11	H. S. Porter Chehalis	E. Vetter R.3 Chehalis	Lewis	Doty Si. C. L.	Potatoes	1931	Tons	7.96	7.49	11.03	10.46	8.85	8.30	7.35	10.07	9.09	10.82	7.15	7.76				
78	H. S. Porter Ridgefield		Clark	Felida Si. L.	Clover	1927	"	1.89				1.52	1.48	1.41				1.61	1.42	1.09			1.40
B32	"	O. Mueller Ridgefield	"	"	Potatoes	1929	"	7.39	8.23	7.26	8.09	8.36	9.56	7.04	8.27	6.48	7.00	7.92	7.44	7.16	8.09	7.09	6.85
C45	"	"	"	"	Wheat	1930	Bushels	43.00	66.00	54.00	74.00	49.00	61.00		65.00	67.00	65.00	58.00	56.00		56.00	76.00	
C43	"	E. Welch Ridgefield	"	"	Alfalfa 2 cuttings	1930	Tons	1.87	2.36	2.84	3.31	1.88											
C71	"	J. Laws Ridgefield	"	"	Alfalfa 1 cutting	1930	"	0.68	1.53	1.36	0.94	0.77											
C3	W. H. Perry Battleground	H. Schlichting Brush Prairie	"	Hesson C. L.	Clover	1930	"	1.47	2.32	3.74	2.80	2.16	2.42	2.91	3.18	3.45	3.34	2.78	3.31	1.10	2.08	3.34	3.21
D3	"	"	"	"	"	1931	"	1.97	2.12	3.35	3.19	2.57	2.72	2.87	3.05	3.05	3.65	3.46	3.03	0.61	3.05	3.33	3.66
D47	C.L.Wellman Washougal	J. Meyer Washougal	"	"	Oat Hay	1931	"	1.80	2.15	2.87	2.04	1.65	1.76										
B111	D.B. Leonard Kelso	E. A. Johnson Castle Rock	Cowlitz	Kelso Si. C. L.	Corn for Silage	1929	"	10.95	13.35	13.23	12.53	11.56											
C107	C. S.Anderson Kelso	"	"	"	Oat Hay	1930	"	2.24	3.10	3.36	3.37	2.52											
C106	"	"	"	"	Pasture 1 cutting	1930	"	0.75	1.43	1.40	1.60	0.74											
B2	W. M. Perry Battleground	C. Meier R.2 Battleground	Clark	Lauren S. L.	Alfalfa	1929	"	0.28	0.85	0.41	1.03	0.52	0.43	0.41	0.49	0.64	0.99	0.39	0.43	0.26	0.93	0.45	0.84
C4	"	Smithline R.D.Battleground	"	Lauren F. S. L.	Oat Hay	1930	"	2.20	3.49	5.50	4.63	1.79	2.30	2.54	4.48	5.20	4.66	2.56	2.06	2.15	5.26	3.87	2.58
D4	"	"	"	"	Clover	1931	"	2.57	2.87	0.91	3.63	3.48	3.18	5.14	3.93	3.95	5.14	3.93	4.69	4.24	4.08	6.35	5.80
C35	W. R. Burt Mossyrock	S. G. DeGoss Salkum	Lewis	Salkum Si. C.	Oat Hay	1930	"	2.40	6.34	5.02	4.65	3.06											
D31	"	"	"	"	"	1931	"	2.18	3.04	4.14	4.24	3.31	3.10										
D32	"	J. Tucker Silver Creek	"	"	"	1931	"	2.06	3.05	3.69	4.61	2.51	3.37										
D13	H. S. Porter Chehalis	H. Wiley R. 3 Chehalis	"	"	Pasture	1931	"	1.21	1.70	2.18	2.18	1.94	1.28	1.21	1.45	1.94	2.16	1.59	1.84				
C31	J. W. Evans R.1 Vancouver	H. Blair R.1 Vancouver	Clark	Sifton Gr. S. L.	Oat Hay	1930	"	2.16	6.53	6.35	6.53	2.42											
D29	"	"	"	"	Clover	1931	"	1.21	1.51	1.51	1.51	1.82	1.56										

composed of material which has been eroded from the lands traversed by the river and its tributaries, whereas most of the other alluvial deposits are formed from residual material eroded from areas traversed by the streams originating in western Washington. In general, the lowland soils derived from residual material, when properly drained, are medium to high in natural productivity. Important agricultural areas of these soils are found in Grays Harbor, Pacific, Lewis, Wahkiakum, Cowlitz, Clark, and Skamania counties. The results of 17 fertilizer experiments conducted on these soils are given in Table 6.

When the yields of the 10 trials with forage crops are arranged according to the natural productivity of the soils, it is found that the results of one experiment should be placed with the group indicated by the lower curve in Figure 9, and that none are high enough to fall within the group indicated by the upper curve. Thus, the yields of nine of the experiments show excellent results from the use of fertilizers. As in the majority of the soil groups previously discussed in this report, the addition of nitrogen resulted in the largest increases in yield, and phosphate or phosphate and potash in combination with nitrogen gave slight additional increases. The cereals harvested for grain responded in a similar manner, but, because of the relatively small number of trials with cereal and forage crops on the different soils in this group, additional fertilizer trials are necessary to verify the trend shown thus far.

7. Organic Soils

Organic soils represent accumulations of organic matter in various stages of decomposition and are known as muck and peat. In muck the process of decomposition is so far advanced that nearly all traces of vegetable fiber have been destroyed and the incorporation of a small percentage of silt and clay with the decomposed organic matter has given the soil a definite consistency. In peat the process of decomposition has not progressed far enough to destroy all the vegetable fiber and, therefore, the original character of the parent material is easily recognized. Muck and peat occupy poorly drained basins where the conditions were favorable for rank growth of water-loving vegetation during the formation of the organic deposits. These soils usually are poorly drained and require artificial drainage to make them suitable for general cropping. Many areas of organic soils are scattered throughout western Washington. Their productivity, even after thorough drainage, is extremely variable, largely on account of differences in decomposition as well as in composition. When muck and peat soils are properly drained and the deficiencies in plant nutrients corrected, they usually are very productive and are exceedingly valuable for certain specialized forms of cropping. Only eight experiments were established on organic soils and the results are presented in Table 7.

Table 6. Results of Fertilizer Treatments on Lowland Soils Derived from Residual Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED: CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
A18	G. O. Baker Elma	J. Olson Elma	Grays Harbor	Chehalis Si. C. L.	Corn Silage	1928	Tons	11.70	10.30	10.02	11.40	14.50	13.60	12.10	12.10	8.60	10.00	14.50	10.50	11.10	10.40	10.90	10.80
B20	E. P. Cooke Menlo	C. Crawford Menlo	Pacific	"	Grass Hay	1929	"	0.42	0.65	0.75	0.68	0.52	0.71	0.36	0.50	0.65	0.85	0.80	0.63	0.50	0.50	0.63	0.45
D23	"	"	"	"	Oat Hay	1931	"	1.81	4.55	4.84	4.64	3.87	3.63	3.68	4.25	4.19	4.55	4.56	4.23	4.55	5.44	4.55	4.55
C9	J. L. Helm Centralia	W.T.Herriford Centralia	Lewis	"	Oats Grain	1930	Bushels	27.00	63.0	83.00	112.0	25.0											
B145	C. G. Izett Cathlamet	L. O. Irving Cathlamet	Wahkiakum	"	Corn Silage	1929	Tons	17.36	16.59	14.75	20.00	16.54											
D182	H. Nelson South Bend	C. Crawford Menlo	Pacific	"	Oat Hay	1931	"	2.94	3.42	3.55	3.13	4.35	2.91										
D18a	H. S. Porter Chehalis	A. Olson Chehalis	Lewis	Chehalis C. L.	Wheat Hay	1931	"	2.30	3.91	3.79	3.92	2.40	3.14	2.09	3.05	3.32	2.92	2.40	3.07				
B113	L. S. Sorensen Montesano	J. H. Taylor Montesano	Grays Harbor	Chehalis Si. C. L.	Kale	1929	"	14.88	21.85	22.80	21.95	18.46											
B114	"	L. Larson Star R. Montesano	"	"	Oats Grain	1929	Bushels	80.00	117.0	159.0	155.0	104.0											
C112	"	E. Glenn R.3 Elma	"	"	Pasture 3 cuttings	1930	Tons	1.61	2.70	3.16	3.28	2.57											
D111	"	J. H. Taylor Montesano	"	"	Oats at nurse crop--pasture	1931	"	3.81	3.63	4.25	4.72	4.92	4.22										
B125	F. D. Yeager Chehalis	T. Nesbit Chehalis	Lewis	"	Wheat Grain	1929	Bushels	74.00	95.00	110.0	87.00			109.0	87.00		76.00			95.00	106.0	104.0	81.0
C129	"	W. Mueller R.1 Chehalis	"	"	Pasture 1 cutting	1930	Tons	0.82	1.31	1.07	1.31	0.43	0.61	0.66	1.58	1.15	0.80		0.45	0.53	1.09	0.89	0.92
D118	"	"	"	"	"	1931	"	0.77	1.18	1.30	1.01	0.65	1.17	0.40	0.91	0.89	1.08	0.61	0.80	0.61	0.89	1.28	0.64
C56	B. L. Brown Woodland	B. S. Yoks Woodland	Cowlitz	Sacramento Si. C. L.	Pasture 2 Cuttings	1930	"	4.13	5.46	6.00	5.83	5.00		4.60	5.75	5.35	5.67	5.08					
D48	"	"	"	"	"	1931	"	2.27	4.07	3.81	4.56	3.13	3.21	2.92	4.43	3.36	3.59	3.10					
C126	F. D. Yeager Chehalis	F. H. Grey R.1 Winlock	Lewis	Winlock Si. C. L.	Wheat Grain	1930	Bushels	15.00	21.0	25.0	22.0	24.0	24.0	29.0	30.00	34.00	35.00	16.00	22.00	24.00	20.00	22.00	[illegible]

Table 7. Results of Fertilizer Treatments on Organic Soils (Peat and Muck)

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED															
								CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
X11	G. O. Baker Elma	Bray Elma	Grays Harbor	Peat	Oat Hay	1926	Tons	1.61				2.42	2.01	1.15				2.18	1.76	1.72			1.56
X2	S. D. Boyer Arlington	Jacob Arlington	Snohomish	"	Oats Grain	1926	Bushels	44.0				75.0	30.0*	52.0				94.0	57.0	73.0			76.0
C48	H. Z. Loomis Roy	H. Kuffel McKenna	Pierce		"	1930	"	37.0	30.0	25.0	30.0	41.0	25.0	11.0	16.0	19.0	26.0	26.0	13.0	24.0	26.0	24.0	15.0
B5	M.H.Pearson Burlington	W. Knutzen Burlington	Skagit	"	"	1929	"	84.0	114.0	77.0	110.0	110.0	92.0	129.0	109.0	86.0	77.0	97.0	126.0	85.0	97.0	87.0	86.0
B136	A. Z. Smith Everett	A.W. Binnall Everett	Snohomish	"	Cabbage	1929	Tons	0.08	0.06	6.25	11.89	13.45											
C143	"	"	"	"	Oat Grain	1930	Bushels	22.0	63.0	92.0	89.0	80.0											
D131	"	"	"	"	Grass Hay	1931	Tons	0.94	0.75	2.30	2.86	3.13	2.58										
Y6	M. Windus Mt. Vernon	Anderson	Skagit	"	Potatoes	1927	"	10.39	11.55			12.37	12.54	11.49				14.06	12.54	11.05			12.71

* Injured by birds.

Widely divergent results were obtained from this limited number of fertilizer trials. In some cases phosphorus appeared to be decidedly the limiting factor, whereas in others potash seemed to be deficient. It is evident that more fertilizer trials are needed on these soils to arrive at definite conclusions.

The Value of Lime on Western Washington Soils

Lime is commonly used as a soil amendment in the older agricultural sections the world over, and its place in the management of western Washington soils is a subject worthy of study. Lime has been included in a relatively large number of experiments but the results obtained have not been uniform. There are some indications that legumes grown on the soils derived from residual material and on some of the coarse soils derived from glacial material were benefited by applications of lime. Although the results as a whole were inconclusive, continued studies with lime in combination with fertilizers are desirable.

Pasture Plot Experiment

As pointed out in the plans of the experiments, a series of six-plot fertilizer trials was established in 1929 in six different locations in western Washington for the purpose of studying the effect of different fertilizers on the yield and composition of pasture grass and hay. In 1930, after the plots had been fertilized two years in succession, the hay and pasture cuttings were obained to determine their composition as well as the yields. In 1931, after three annual applications of fertilizers, only the yields were obtained. It should be noted that the rate of application of fertilizers in 1930 and 1931 was one-half that of 1929 so that the actual amounts applied during the years when yields were obtained were rather small, as can be seen from the data in Figure 7. The fertilizer experiments were on representative soils, three on lowland soils derived from glacial material, one on a lowland soil derived from residual material, and two on peat soils. The average yields of the pasture cuttings and the yields of hay on the different soils are recorded separately in Table 8. The composition of these materials in terms of protein, calcium, phosphorus, and potassium is given in Table 9.

There are many interesting points in these results. One is that the response of these crops to the various fertilizers is not the same on all soils. For instance, it is obvious that both phosphorus and lime produced marked beneficial effects on two of the soils, one a lowland soil derived from glacial material and the other a lowland soil derived from residual material, and no particularly outstanding effects on the other soils. This variation in response serves to emphasize the importance of the soil itself in considering the proper use of fertilizers.

Table 8. Results of Fertilizer Treatments on Pastures on Different Soils

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELDS EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED: CHECK	P	PK	PKL	NPKL
C301	Clay A. Whybark Soils Section	Herman Anderson Eatonville	Pierce	Bellingham Si. L.	Pasture 2 cuttings	1930	Tons	1.37	1.54	2.04	2.18	1.87
C301	"	"	"	"	Hay 1 cutting	1930	"	1.71	2.40	2.26	2.62	2.65
D301	"	"	"	"	Pasture 2 cuttings	1931	"	1.73	1.92	1.89	2.28	2.17
D301	"	"	"	"	Hay 1 cutting	1931	"	2.14	2.01	1.91	2.58	2.60
C302	"	Alexander Chehalis	Lewis	Chehalis Si.C.L.	Pasture 2 cuttings	1930	"	1.54	1.81	1.67	2.01	2.34
C302	"	"	"	"	Hay 1 cutting	1930	"	2.65	3.42	2.58	2.45	2.54
D302	"	"	"	"	Pasture 2 cuttings	1931	"	1.70	2.34	1.86	2.05	2.32
D302	"	"	"	"	Hay 1 cutting	1931	"	2.32	2.60	2.70	2.72	2.65
C303	"	Frank Krones Eatonville	Pierce	Peat	Pasture 3 cuttings	1930	"	2.97	3.02	3.49	3.60	4.23
C303	"	"	"	"	Hay 1 cutting	1930	"	3.31	3.14	3.92	3.84	4.10
D303	"	"	"	"	Pasture 2 cuttings	1931	"	4.21	3.48	4.44	4.47	4.24
D303	"	"	"	"	Hay 1 cutting	1931	"	3.48	3.02	4.00	3.15	3.42
C304	"	McCord Lynden	Whatcom	"	Pasture 3 cuttings	1930	"	3.10	3.17	4.15	4.22	5.39
C304	"	"	"	"	Hay 1 cutting	1930	"	2.24	2.24	3.38	2.88	3.38
D304	"	"	"	"	Pasture 2 cuttings	1931	"	2.35	2.67	3.34	2.89	2.99
D304	"	"	"	"	Hay 1 cutting	1931	"	3.02	2.42	4.16	3.39	4.37
C305	"	W.O. Cedergreen Snohomish	Snohomish	Puget Si.C.	Pasture 3 cuttings	1930	"	2.82	2.67	2.92	2.93	3.43
C305	"	"	"	"	Hay 1 cutting	1930	"	2.65	3.08	3.07	3.00	4.30
D305	"	"	"	"	Pasture 3 cuttings	1931	"	3.97	3.91	4.09	4.75	5.19
D305	"	"	"	"	Hay 1 cutting	1931	"	2.57	2.83	2.33	2.96	3.26
C306	"	N.O. Ekstran Bow	Skagit	"	Pasture 2 cuttings	1930	"	2.49	2.72	2.96	2.79	3.22
C306	"	"	"	"	Hay 1 1 cutting	1930	"	3.43	3.92	3.98	4.81	3.63
D306	"	"	"	"	Pasture 2 cuttings	1931	"	1.91	1.79	2.13	1.85	2.57
D306	"	"	"	"	Hay 1 cutting	1931	"	2.17	1.42	2.61	2.56	4.11
			Average yield of pasture cuttings				*	2.51	2.59	2.91	2.99	3.33
			Average yield of hay cuttings				"	2.64	2.70	3.07	3.06	3.41

* Calculated from green weight.

Another interesting point is the varying effect of the different fertilizers on the composition of the pasture and hay produced on the different soils, and also on the composition of the different pasture cuttings. These various factors, together with other analytical data obtained in this experiment but not presented here will be discussed in detail in a separate publication. From a practical standpoint it seems best to consider the results on the basis of averages, as was done previously with the data obtained in the other fertilizer trials in this report.

Table 9. Composition of Pasture and Hay Cuttings from the Pasture Fertilizer Plots in 1930.(Per cent of dry matter)

Nutrient Element	Plot	Soil Type	Pasture* Check	Pasture* P	Pasture* PK	Pasture* PKL	Pasture* NPKL	Hay Check	Hay P	Hay PK	Hay PKL	Hay NPKL
			Fertilizer Treatments									
Protein	C301	Bellingham Si.L.	16.31	15.27	15.26	16.89	14.20	8.34	9.40	10.93	9.56	6.97
	C302	Chehalis Si. C. L.	11.84	13.89	11.89	12.98	11.42	8.15	9.65	10.15	7.75	5.96
	C303	Peat	15.80	16.18	16.37	15.13	15.05	8.84	8.90	9.34	8.72	10.50
	C304	Peat	15.15	17.30	13.97	12.98	12.49	10.34	11.62	10.46	9.50	8.87
	C305	Puget Si. C.	13.95	15.30	16.10	16.90	15.74	9.62	8.59	9.40	9.25	8.53
	C306	Puget Si. C.	12.97	12.72	12.44	13.20	13.62	8.40	7.15	8.31	8.40	8.71
	AVERAGE		14.33	15.14	14.33	14.68	13.75	8.95	9.22	9.77	8.86	8.26
Calcium	C301	Bellingham Si. L.	.41	.36	.36	.49	.42	.48	.39	.60	.67	.47
	C302	Chehalis Si. C. L.	.40	.41	.50	.55	.54	.26	.53	.96	.95	.89
	C303	Peat	.51	.50	.47	.66	.64	.55	.73	.59	.64	.80
	C304	Peat	.62	.56	.67	.71	.74	.80	.71	.61	.61	.66
	C305	Puget Si. C.	.63	.60	.61	.64	.65	.96	.91	.76	1.16	.89
	C306	Puget Si. C.	.30	.31	.23	.29	.28	.50	.49	.41	.54	.56
	AVERAGE		.48	.46	.47	.56	.55	.59	.63	.66	.76	.71
Phos-phorus	C301	Bellingham Si. L.	.45	.43	.42	.45	.43	.28	.31	.30	.29	.21
	C302	Chehalis Si. C. L.	.33	.41	.39	.39	.37	.25	.29	.26	.26	.24
	C303	Peat	.30	.40	.38	.35	.35	.27	.36	.31	.29	.32
	C304	Peat	.24	.37	.30	.29	.27	.09	.27	.25	.22	.23
	C305	Puget Si. C.	.34	.41	.44	.44	.42	13	.22	.17	.24	.17
	C306	Puget Si. C.	.39	.45	.48	.50	.51	.41	.38	.31	.50	.47
	AVERAGE		.34	.41	.40	.40	.39	.24	.31	.27	.30	.27
Potassium	C301	Bellingham Si. L.	1.53	2.69	2.58	2.57	2.74	.84	.56	1.01	1.07	.71
	C302	Chehalis Si. C. L.	2.34	3.04	2.71	2.71	3.23	1.85	1.96	2.21	2.30	2.07
	C303	Peat	.92	.87	1.38	1.38	.88	1.14	.83	1.78	1.83	1.50
	C304	Peat	2.27	2.42	2.83	3.33	3.20	.12	.73	1.49	.82	.85
	C305	Puget Si. C.	1.54	1.58	1.86	2.32	2.35	1.42	1.37	2.23	2.42	1.84
	C306	Puget Si. C.	2.07	2.35	2.57	2.86	3.01	3.05	2.65	2.17	3.41	3.46
	AVERAGE		1.78	2.16	2.32	2.53	2.57	1.40	1.35	1.82	1.98	1.74

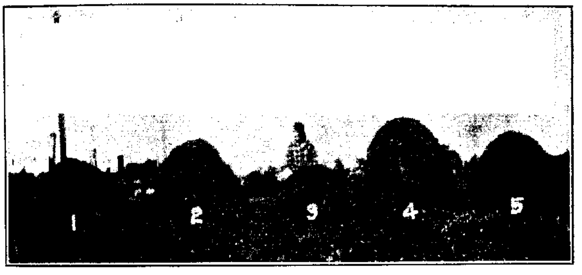
* Average of cuttings.

Yields of Pasture Grass and Hay

The average yields of pasture cuttings and hay on the check plots indicate that the soils are medium in productivity, but the increases in yield resulting from the fertilizer treatments are not as good as those represented by the central curve in Figure 9, due undoubtedly to the lower rate of applications, especially of nitrogen and phosphate fertilizers. This is clearly demonstrated when a comparison is made of the yields of hay obtained in this experiment with those of the same crop in many of the other experiments on similar soils, which, however, received twice as much nitrogen and twice as much phosphate. The average increase in yield resulting from the application of the complete fertilizers, consisting of 125 pounds of ammonium sulfate, 300 pounds of superphosphate, 100 pounds of sulfate of potash, and 500 pounds of lime per acre, amounted to about 32 per cent for the pasture cuttings and 29 per cent for the hay. The response of these crops to the other fertilizer treatments is also very satisfactory, as can be seen from the figures in Table 8 and the yield curve in Figure 10.

Plant Nutrient Contents of the Crops

Aside from the effect of the various fertilizers on yield, it is interesting to note their effect on the quality or composition of both pasture and hay. With few exceptions the protein, calcium, phosphorus, and potassium content of these crops was distinctly increased when lime or phosphate, or potash fertilizers, were applied alone and



1 = N; 2 = NP; 3 = Check; 4 = NPK; 5 = PK.

Results on Pasture on a Soil of Medium Natural Productivity where It Pays to Use the Proper Kinds of Fertilizers.

The total yields of three cuttings of pasture grass in one season show that the use of a combination of nitrogen and phosphate on a lowland soil derived from residual material increased the yield from 1.61 tons of dried pasture grass per acre to 3.15 tons, or an increase of about 91 per cent. The plot receiving complete fertilizer yielded at the rate of 3.28 tons per acre.

in combinations to the soil. The protein content of the crops, however, was not similarly affected when nitrogen was added as a fertilizer. In these cases the yields were markedly increased, suggesting that the small amounts of nitrogen added in the form of fertilizer were utilized in increased growth, which in turn had a tendency to decrease slightly the percentages of calcium, phosphorus, and potassium in the crops but not the total amounts of these elements taken out of the soil. This is shown in Table 10 where the average total amounts of nutrient elements have been calculated and recorded.

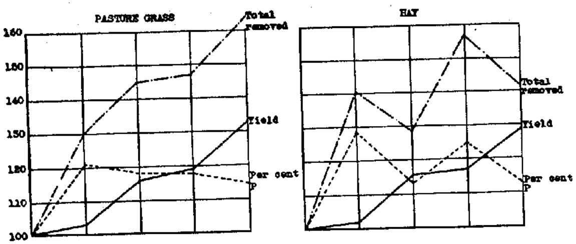
Effect of Fertilizers on the Yield and Composition of Pasture Grass and Hay

A clear picture of the effect different fertilizers may be expected to exert on the yield and composition of pasture grass and hay, and on the amount of plant nutrients removed from the soil, can be reproduced graphically when the different values such as tons for yield, percentage for composition, and pounds for plant nutrients removed are reduced to a common basis. Thus, the average acre yield of pasture grass on the check plots, which is 2.51 tons, has been given the value of 100, and the increases in yield resulting from the fertilizer treatments in the other plots are given values greater than 100 in the exact proportion that the tonnage recorded in Table 8 is greater. The percentage of each nutrient element in pasture grass and hay on the check plots also has been taken as 100, and the increase or decrease, as the case may be, resulting from the fertilizer treatments is given a value greater or smaller than 100 in the exact proportion that the percentages in Table 9 are greater or smaller than those of the check plots. Similarly, the average amount of each nutrient element removed from the soil by the pasture grass on the check plots has received the value of 100, and the increases or decreases resulting from the application of fertilizer received values greater or smaller in the same proportion that the amounts recorded in Table 10 are greater or smaller than those of the check plots. The same has been done for the hay, and the results are illustrated in Figure 10.

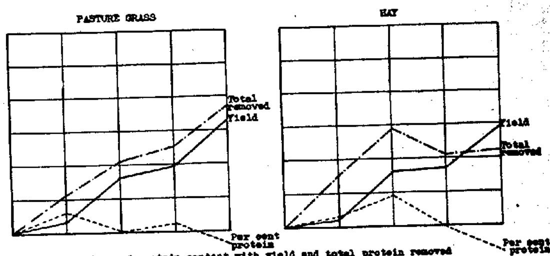
In comparing the percentage composition of protein in the pasture grass with the yield and with the protein taken from the soil as nitrogen, it is shown that the application of phosphate alone resulted in a larger protein content of the young grass, in a definite increase in yield, and in a larger removal of nitrogen from the soil. When a combination of phosphate and potash fertilizers was added to the soil, both the yield and total amount of nitrogen removed were further increased but the per cent protein in the grass was decreased. The addition of lime in combination with phosphate and potash fertilizers again increased the yield and the amount of nitrogen removed. It also

Table 10. **Average Yields of Pasture Grass and Hay per Acre and Average Amounts of Protein, Calcium, Phosphorus, and Potassium Removed from the Different Soils**

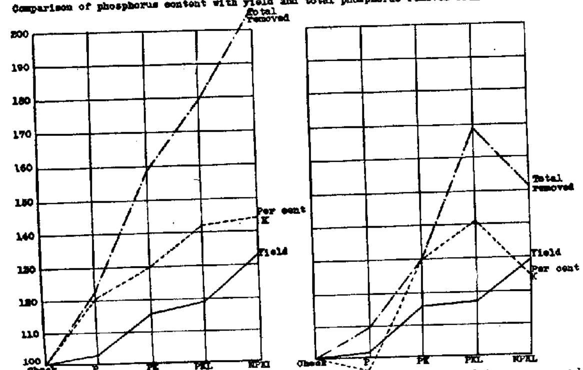
	Pasture						Hay					
		Nutrients removed in pounds per acre						Nutrients removed in pounds per acre				
Treatment	Yield in tons	Protein	Calcium	Phosphorus	Potassium	Total	Yield in tons	Protein	Calcium	Phosphorus	Potassium	Total
Check	2.51	687.0	23.8	15.6	83.2	809.6	2.64	476.6	31.3	13.3	82.0	603.2
P	2.59	759.5	23.4	20.3	101.8	905.1	2.70	546.7	37.8	18.8	89.7	693.0
PK	2.91	833.1	28.2	22.6	131.3	1015.2	3.07	616.0	40.6	17.2	106.9	780.6
PKL	2.99	858.3	34.0	23.0	149.0	1064.3	3.08	576.8	48.0	20.9	138.3	783.9
NPKL	3.33	940.3	39.6	25.6	171.3	1176.9	3.41	580.8	49.4	18.9	123.5	772.7



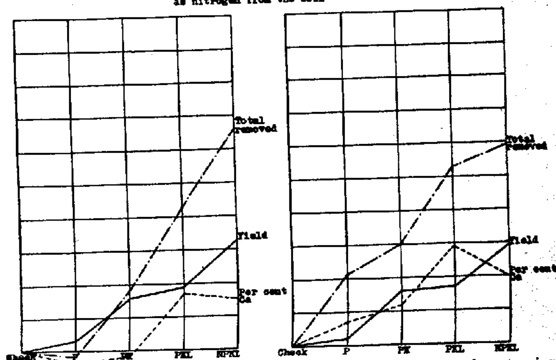
Comparison of phosphorus content with yield and total phosphorus removed from the soil



Comparison of protein content with yield and total protein removed as nitrogen from the soil



Comparison of calcium content with yield and total calcium removed from the soil



Comparison of potassium content with yield and total potassium removed from the soil

Fig. 10. Comparison of the Average Protein, Calcium, Phosphorus, and Potassium Content of Pasture Grass and Hay with the Average Crop Yields and the Average Amounts of Nutrient Elements Removed from the Soil.

slightly increased the protein content of the grass. The use of complete fertilizer with lime resulted in the largest yield and in the greatest removal of nitrogen from the soil, but the protein content of the grass was less than that of the check plots. The effect of the fertilizers on hay, although slightly different in certain respects, was quite comparable with that on pasture grass.

A similar comparison of the calcium content of the pasture grass and hay shows that phosphate fertilizers applied alone caused a decrease in both the calcium content of the pasture grass and the total quantities of this element removed from the soil, but a different effect was produced in the hay in that it contained a smaller percentage of calcium and removed greater quantities from the soil. A combination of phosphate and potash fertilizers, while raising the yield, also slightly increased the calcium content of the pasture grass and greatly increased the total amount of calcium taken from the soil, whereas with the hay both the calcium content and total amount removed were markedly increased. Where lime was added in combination with phosphate and potash or with the complete fertilizer, the calcium content and the total amount removed from the soil by the pasture grass and the hay were much increased. However, the percentage of calcium in both crops was somewhat offset by the greater yield resulting from the application of complete fertilizer.

The same comparison of the phosphorus content of the pasture grass and of the hay shows similar features in a somewhat varying degree. It is of special interest to note, however, that the application of phosphate fertilizers alone or in combination with other fertilizers invariably resulted in a marked increase in the phosphorus content of the crops. This increase ranged from about 15 to 20 per cent for the pasture grass and from approximately 13 to 29 per cent for the hay.

A comparison of the potassium content of these forage crops with the yields and the quantities of potassium removed from the soil also brings out many interesting points, although perhaps they may not be very important from the standpoint of the direct feeding value of the crops since the function of potassium in animal nutrition is not well known.

Significance of the Effect of Fertilizers on Pasture Grass and Hay

The results in connection with the protein, calcium, and phosphorus contents of the pasture grass and hay are very significant in regard to the quality of forage crops as cattle feed, especially of those grown in areas where mineral deficiencies or improper ratios of the mineral nutrients in forages are likely to occur. Although not definitely proved, it is strongly suspected that some of the prevailing nutritional disorders in dairy cattle in western Washington are traceable to mineral deficiencies in the feeds, notably calcium and phosphorus

deficiencies. It is encouraging to note that the calcium and phosphorus content, as well as the yield of pasture and hay, can be increased rather easily by the use of fertilizers, as has been indicated by the results presented in this report.

In averaging the yields and also the amounts of plant nutrients utilized by pasture grasses and hay, the interesting fact is brought out that, although the hay produced a larger amount of dry matter per acre than the pasture, the total amount of the different plant nutrients removed from the soil by the pasture grass is far in excess of that removed by the hay. The data are presented in Table 10. It is indicated that, on an average, the pasture produced per acre in this experiment contained from 206 to 308 pounds more protein, calcium, phosphorus, and potash than the hay, showing that the pasture grass required approximately 35 to 40 per cent more of these plant nutrients than the hay. This explains in part why pasture is a better livestock feed than hay, and is important in relation to pasture soil management because it distinctly indicates the heavy demands that this crop makes on soil fertility.

It should be stated also in this connection that the flora of pastures may be changed considerably through the use of fertilizers. On some of the soils, notably the lowland soils derived from glacial material, the use of a combination of phosphate, potash, and lime in the course of two years caused a change in the flora from a predominance of native brome and fescue grasses and weeds to one comprising approximately 40 per cent clover. Thus, the flora in certain pastures may be greatly improved and very much changed by the proper utilization of fertilizers.

Judging from the results of the pasture plot experiments, it is reasonable to conclude that the proper use of fertilizers on pastures in western Washington on medium yielding soils well supplied with moisture throughout the growing season is good farm practice, not only because it increases the yields but also because it improves the quality of the pasture grasses, especially in regard to mineral content, notably that of calcium and phosphorus.

Soil Groups of Eastern Washington

1. Irrigated Terrace Soils Derived from Alluvial Material

Experimental plots were laid out in the majority of the irrigated areas, but because of the great variation in soils it seems best to discuss the results of the fertilizer trials in each area separately. Therefore, the data presented in Table 11 pertaining to the trials in each area have been listed separately.

Ellensburg District: A total of 21 fertilizer trials was established in this area and of this 16 were on alfalfa. The response was greatest

Table 11. Results of Fertilizer Treatments on Irrigated Terrace Soils Derived from Alluvial Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL CLASS	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED: CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
B 112	E.L.Harms Waterville	O.J.Ross Orondo	Douglas	not classified	alfalfa 2 cuttings	1929	Tons	3.93	4.72	3.78	4.18	4.18											
ELLENSBURG DISTRICT																							
C 21	J.A.Johnson Ellensburg	H.E.Hansen R.1 Ellensburg	Kittitas	not classified	Potatoes	1930	Tons	10.38	13.80	13.95	18.42	14.34											
D 21	"	F.F.A.Chapter Ellensburg	"	"	"	1931	"	6.98	11.29	9.18	11.96	7.02	6.02										
B 118	W.O.Passmore Ellensburg	Clarence Jones Ellensburg	"	"	Alfalfa 2 cuttings	1929	"	4.80	5.15	4.83	6.59	5.22											
B118A	"	S.Woodhouse R.2 Ellensburg	"	"	"	"	"	4.41	5.46	7.50	7.94	6.91											
C 120	"	"	"	"	"	1930	"	3.63	4.41	7.96	7.60	6.86											
D 115	"	"	"	"	Wheat hay	1931	"	5.08	5.61	8.11	8.18	7.99	5.02										
B 119A	"	Fred Drake R.3 Ellensburg	"	S. L.	Alfalfa 2 cuttings	1929	"	3.19	2.94	3.50	3.92	3.92											
C 119	"	"	"	"	Alfalfa 1 cutting	1930	"	2.82	2.70	3.68	3.80	4.04											
D*	"	"	"	"	Alfalfa 1st cutting	1931	"	2.42	3.03	3.75	3.63	3.87											
B 120	"	Will Haberman Ellensburg	"	"	Alfalfa 2 cuttings	1929	"	3.92	5.81	7.67	6.05	2.03											
B 120A	"	A. Sorenson Ellensburg	"	"	Alf. & Tim. 2 cuttings	1929	"	7.52	7.28	7.91	7.56	7.77											
B 121	"	Will Lawrence R.3 Ellensburg	"	Gr. S.L.	Alfalfa 2 cuttings	1929	"	4.19	4.14	6.30	6.05	5.83											
C 121*	"	"	"	"	Alfalfa 1st cutting	1930	"	1.72	2.45	2.94	3.92	4.66											
D121**	"	"	"	"	"	1931	"	1.45	1.94	2.42	2.66	2.76											
B 121A	"	A.Tjossem R.2 Ellensburg	"	not classified	Alfalfa 2 cuttings	1929	"	5.10	4.73	5.76	5.34	5.76											
C121A*	"	"	"	"	Alfalfa 2nd cutting	1930	"	1.59	1.72	2.33	2.57	2.70											
B 122	"	J. O.Sorenson Ellensburg	"	"	Alfalfa 2 cuttings	1929	"	3.80	4.41	6.54	6.30	6.25	5.81	4.21	4.41	6.54	6.30	6.25	5.81	5.88	5.27	5.27	5.88
C 115	"	Sam Stampfly R.3 Ellensburg	"	Gr. S. L.	Alfalfa 2nd cutting	1930	"	0.74	0.86	2.08	2.08	2.57											
D 118	"	"	"	"	Alfalfa 2 cuttings	1931	"	2.98	3.16	5.49	5.32	5.40											
C 116	"	A.J.Dunnington R.4 Ellensburg	"	S. L.	Alf. & Tim. Hay	1930	"	4.71	4.16	3.92	5.40	4.71											
D 116*	"	"	"	"	"	1931	"	3.87	4.84	3.87	4.60	4.60											
C 121	"	J.C.Sorenson R.2 Ellensburg	"	"	Alfalfa 2nd cutting	1930	"	1.18	1.30	1.96	1.96	1.59											
D 121*	"	"	"	"	"	1931	"	1.45	1.60	1.94	2.18	2.30											

* No fertilizer applied. Results show residual effect of fertilizers applied the previous year.
** No fertilizer applied for 2 years. Results show residual effect of fertilizers.

Table 11. (Cont.) Results of Fertilizer Treatments on Irrigated Terrace Soils Derived from Alluvial Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL CLASS	CROP	YEAR	YIELDS EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED															
								CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
D 117	W.O.Passmore Ellensburg	B.O.Nelson R.1 Ellensburg	Kittitas	S. L.	Alfalfa 2 cuttings	1931	Tons	6.29	5.50	6.78	7.02	7.38	6.53										
C 118	"	Lee Simmons R.2 Ellensburg	"	"	Potatoes	1930	"	8.54	10.36	10.15	7.75	8.05											
C 128	"	V.T.Stevens R.2 Ellensburg	"	"	Alfalfa 1 cutting	1930	"	1.05	1.83	2.33	1.96	1.84											
YAKIMA VALLEY																							
B 48	D.R.Canfield Yakima	V.Lutthans R.4 Yakima	Yakima	not classified	Corn fodder	1929	Tons	2.61	2.85	2.55	2.32	2.41											
C 69	"	Jack Hansen R.4 Yakima	"	"	Potatoes	1930	"	23.02	22.52	22.76	21.78	21.86											
B 203	H.P.Singleton Prosser	Ed. Rodie Sunnyside	"	"	Corn	1929	Bushels	87.0	81.0	85.0	72.0	64.0											
B 202	"	B.F.Williams Grandview	"	F.S.L.	Potatoes	1929	Tons	8.07	9.53	9.10	10.53	8.11											
C 202	"	"	"	"	"	1930	"	8.10	9.37	11.15	10.19	6.71											
B 204	"	A.M.Skinner Sunnyside	"	"	"	1929	"	13.12	11.26	10.43	11.41	13.06											
C 203	"	"	"	"	"	1930	"	12.50	10.68	8.45	9.54	11.76											
LOWER YAKIMA VALLEY																							
C 27	W.L.Barbee Kennewick	Chas.Carpenter Kennewick	Benton	F.S.L.	Grapes	1930	Tons	5.17	6.75	5.21	6.42	3.97											
C 26	"	Jim Hill Kennewick	"	"	Prunes	1930	"	9.72	10.50	7.29	6.21	10.23								3.01	4.37		
D 25	"	"	"	"	"	1931	"	3.19	5.65	5.51	5.15	4.89	3.94										
C 103	R.C.Durdle Kennewick	W.C.Swayze Kennewick	"	"	"	1930	"	5.75	6.85	9.08	7.33	6.90											
B 103	"	E.M.Aylward R.1 Kennewick	"	not classified	Alfalfa 4 cuttings	1929	"	9.91	9.10	10.00	10.07	10.07	9.75	9.78	9.82	9.93	10.16	9.64	10.10	9.64	8.88	9.37	9.92
B 105	"	Jens Lande R.1 Kennewick	"	"	"	1929	"	8.79	7.79	10.00	9.11	9.07											
C 101	"	"	"	"	Alfalfa 3 cuttings	1930	"	3.50	3.31	4.44	4.85	4.78											
D 101	"	"	"	"	Alfalfa 2 cuttings	1931	"	2.26	2.44	4.98	4.95	4.15	4.45										
B 106	"	W.L.Enyeart Hanford	"	F.S.	Alfalfa 3 cuttings	1929	"	6.31	9.16	11.03	11.38	9.97											
C 102	"	"	"	"	"	1930	"	4.79	5.19	6.85	7.50	6.52											
D 110	T.M.Ingham Pasco	J.A.Bell Pasco	Franklin	S.L.	Alfalfa 2 cuttings	1931	"	3.74	4.25		4.24	3.53	4.17										

Table 11 (Concl.) Results of Fertilizer Treatments on Irrigated Terrace Soils Derived from Alluvial Material

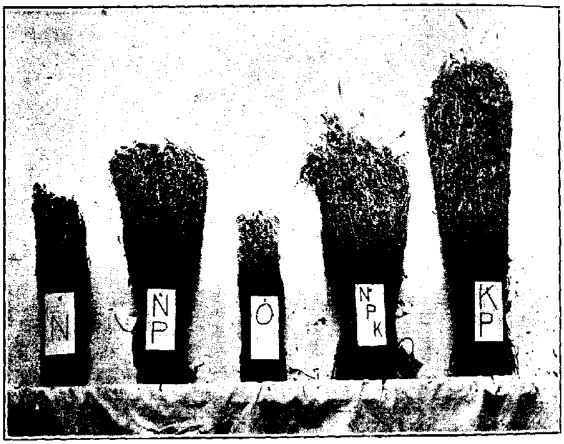
PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL CLASS	CROP	YEAR	YIELDS EXPRESSED IN	ACRE YIELDS FROM TREATMENTS AS INDICATED															
								CHECK	N	NP	NPK	PK	P	L	NL	NPL	NPKL	PKL	PL	K	NK	NKL	KL
WALLA WALLA AREA																							
D 136	H.C.Burgess Walla Walla	G.L.Gray Touchet	Walla Walla	S.L.	Alfalfa & Bar. 2 cuttings	1931	Tons	2.91	3.48	3.33	3.29	2.91	3.21										
D 134	"	James Locati R.2 Walla Walla	"	not classified	Onions	1931	Sacks	660.0	560.0	720.0	680.0	680.0	540.0										
D 135	"	Arbini Bros. Walla Walla	"	"	"	1931	"	360.0	460.0	480.0	480.0	500.0											
B 147	A.W.Kasten Walla Walla	Loomis Locker R.1 Lowden	"	F.S.L.	Alfalfa 2 cuttings	1929	Tons	5.25	5.08	4.78	4.85	5.31											
C 150	"	"	"	"	Alfalfa 1st cutting	1930	"	1.57	2.60	2.70	3.07	2.90											
B 42	H.Mewhinney Walla Walla	Louis Esmieu 433 Green St.	"	Si. L.	Prunes	1929	"	8.33	10.13	10.58	11.05	8.78											
C 60	W.R.Sheff Walla Walla	"	"	"	"	1930	"	8.78	9.00	9.23	9.00	7.50											
(1) D 45	C Lybecker Walla Walla	"	"	"	"	1931	"	1.42	2.65	2.74	1.91	1.41											
D 46	"	D.Gilkerson R.5 Walla Walla	"	not classified	Potatoes	1931	"	18.73	17.04	18.44	24.80	25.07	17.18										

(1) Frost injury.

from the phosphate treatments, although in many cases the addition of nitrogen also resulted in marked increases in yields. A distinct response from potash fertilizers was observed in only five of the experiments. This shows that apparently the main deficiency for alfalfa in the soils of this district is available phosphorus, and perhaps in some cases sulfur, since superphosphate, which was used as the phosphate carrier, contains appreciable amounts of sulfate. The response from superphosphate was so definite, however, that the use of this fertilizer on soils that are not producing satisfactory yields of alfalfa appears to be sound farm practice.

It is interesting to note the large number of cases where the yields were increased by the application of nitrogen fertilizer. Ordinarily it is assumed that a legume, and especially alfalfa, on irrigated soils which usually are thoroughly inoculated, derives most of its nitrogen from the air through the medium of the nodule bacteria on the roots. This apparently was not the case in these experiments and the explanation for the results obtained is not entirely clear.

In all the experiments reported so far, the results were obtained the same year the fertilizers were applied and no account was given



A Striking Effect of Superphosphate on the Growth of Alfalfa

Second cutting of alfalfa on an irrigated terrace soil derived from alluvial material. The untreated soil yielded 0.74 tons, that fertilized with nitrogen 0.86 tons, that receiving nitrogen and phosphate 2.08 tons, and the one treated with a combination of phosphate and potash fertilizers 2.57 tons of hay per acre.

of their possible residual effect on yield. On five of the experiments in the Ellensburg district yields were obtained the following year without renewing the fertilizer treatments, and in one case the second year after the fertilizers were applied. The residual effect of the treatments is rather striking, and indicates that the plant food added by means of the fertilizers was not entirely used up the first year. The average yields computed from these six experiments show that the greatest residual effect was obtained on the PK plots. This effect was nearly as great, however, on the NPK plots and somewhat less on the NP plots.

The results of the three experiments with potatoes are inconclusive although a very satisfactory response was obtained from complete fertilizer in one of the trials. Additional studies with potatoes in this district will probably give more definite results.

Yakima Valley: This includes the area from Sunnyside to Yakima. Very little if any definite response was obtained in the seven experiments with potatoes and corn. This may be due to the fact that alfalfa was plowed under previous to planting these crops. In some cases the soils were somewhat alkali and this undoubtedly interfered with the results.

Lower Yakima Valley: The lower Yakima valley comprises the general area around Pasco and Kennewick. The results of the seven experiments with fertilizers on alfalfa show that the response is almost entirely limited to phosphate treatments. The results with prunes seem to indicate a nitrogen deficiency, but since damage by late spring frosts is not uncommon in this area this factor may have interfered with the uniformity of the response.

Walla Walla Area: The nine experiments with fertilizers on various crops in this area show that on an average the best response was obtained from the nitrogen-phosphate combinations. Nitrogen alone, however, seemed to benefit prunes and onions.

Although the results obtained in the Yakima and lower Yakima valleys, and in the Walla Walla area show certain trends, they are inconclusive as a whole. Therefore, it will be necessary to continue the experiments before definite conclusions can be reached.

2. Terrace and Lowland Soils Derived from Glacial or Residual Material

The soils of this group are found in Spokane, Stevens, and Pend Oreille counties. Only 17 experiments were located in the entire area and, therefore, must be interpreted arbitrarily until more experimental evidence is available. The limited data presented in Table 12 show that the soils on which the experiments were conducted in Spokane and

Table 12. Results from Fertilizer Treatments in Northeastern Washington on Terrace and Lowland Soils Derived from Glacial or Residual Material

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	ACRE YIELDS FROM TREATMENTS INDICATED						
								CHECK	N	NP	NPK	PK	P	
B 139	Robert Cowan Spokane	E.P. McCarthy Deer Park	Spokane	Unknown	Wheat grain	1929	Bushels	21.0	23.0	28.0	32.0	21.0		
B 131	S. E. Hupp Newport	C. H. Parks Usk	Pend Oreille	Not classified	Alfalfa 1 cutting	1929	Tons	1.66	2.33	3.14	3.02	3.06		
C 133	"	"	"	" "	"	1930	"	2.03	3.70	2.40	2.54	1.63		
D 125	"	"	"	" "	Barley grain	1931	Bushels	39.0	55.0	67.0	72.0	48.0	41.0	
B 131A	"	E.E.Hupp Newport	"	"	Potatoes	1929	Tons	9.0	14.50	12.74	16.54	12.61		
C 134	"	"	"	"	"	1930	"	5.09	9.75	10.45	7.13	3.68		
D 124	"	"	"	"	Barley grain	1931	Bushels	22.0	46.0	48.0	55.0	25.0	22.0	
B 130	"	Paul Berendt Cusick	"	"	Grass hay	1929	Tons	0.10	0.84	1.00	1.36	0.58		
C 136	"	"	"	"	Oats grain	1930	Bushels	44.0	59.0	104.0	112.0	66.0		
C 159	"	H. J. Blake R.1 Newport	"	"	Wheat hay	1930	Tons	0.36	0.49	0.68	0.79	0.46		
C 158	"	D.M. Edens R.2 Newport	"	"	Potatoes	1930	"	4.08	3.02	4.36	4.92	4.68		
C 11	George Isaman Chewelah	D.B. Logan Chewelah	Stevens	Unknown	Grass hay	1930	"	2.66	2.84	2.70	2.74	2.19		
B 23	Paul K. Jones Millwood	J.A.Lunneborg R.3 Hillyard	Spokane	"	Potatoes	1929	"	16.13	12.70	15.73	11.60	12.70		
C 30	"	V.A.Brinnon R.6 Spokane	"	"	Wheat grain	1930	Bushels	34.0	32.0	29.0	28.0	28.0		
D 133	A.K.Millay Colville	Frank Habein Colville	Stevens	"	Barley hay	1931	Tons	4.30	2.65	3.24	3.60	3.52	3.56	
C 13	R.C.Patrick Colville	H.T.Skeels Colville	"	"	Oat hay	1930	"	2.87	4.46	4.69	3.78	3.76		
D 16	"	"	"	"	Oat and pea hay	1931	"	1.95	2.37	2.78	2.84	2.95	1.56	

Stevens counties did not respond to fertilizer treatments to any marked extent. Those in Pend Oreille county responded favorably, however, in the majority of the trials. The best responses were obtained from nitrogen, but in several cases the complete fertilizers and the nitrogen in combination with phosphate resulted in additional increases in yield.

3. Soils of the Palouse Formation

Attention has already been called to the fact that the fertilizer trials on soils of the Palouse formation were almost entirely limited to the area where the annual precipitation is 18 inches or more. These trials were designed chiefly for the purpose of determining the rate of application of nitrogen fertilizers that would give the most economical returns on hilltops and upper slopes where the yellow subsoil is either exposed or within the depth of average plowing and where available nitrogen is known to be a limiting factor in yield. It will be recalled that three different rates of application of nitrogen fertilizers were used. Mention should be made of the fact that the experiments were on winter wheat, that the fertilizers were applied by broadcasting, and that the time of application was as early in the spring as possible in order to give the fertilizer an opportunity to dissolve thoroughly in moist soil and be carried down to the root zone by spring showers. A total of 44 of these experiments was established, largely on upper slopes and hilltops in the Palouse area. The results are given in Table 13.

The data show that there is considerable variation in the yields of the check plots as well as of the fertilized plots. A large part of this variation is due to the location of the plots. When the yield of the check plot is extremely low it may generally be assumed that the experiment was on a hilltop, but when the yield of the check plot is exceptionally high it is almost certain that the experiment was located on a lower slope.

Averages of the yields show that the check plots produced 28 bushels of wheat per acre, the plots receiving the lowest quantities of nitrogen fertilizer yielded 33 bushels per acre, the plots receiving the second rate of fertilizer treatment yielded 36 bushels per acre, and those receiving the largest amount of fertilizers produced 37 bushels of wheat per acre. The actual average returns per 100 pounds of nitrate of soda applied to the soil were 3.3 bushels on the plots treated with 150 pounds of nitrogen fertilizer per acre, 3.2 bushels for the 250 pound rate of fertilizer application, and only 2.6 bushels for the plots receiving 350 pounds of nitrogen fertilizer per acre. Thus, the results show that the application of either 150 or 250 pounds of nitrate of soda per acre gave approximately the same returns in increased yields

Table 13. Results from Application of Nitrogen Fertilizers on Soils of the Palouse Formation

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	POUNDS OF SODIUM NITRATE PER ACRE CHECK	180	250	350
B 8	E. M. Webb Dayton	Vern McLarry Dayton	Columbia	not classified	Wheat	1929	Bushels		30.0	30.0	42.0
B 15	N.C.McClure Fairfield	W.W.Cupp Mt. Hope	Spokane	Palouse Si. L.	"	"	"	19.0	20.0	26.0	29.0
B 16	"	F.G.Pottratz Waverly	"	"	"	"	"	16.0	37.0	43.0	46.0
B 28	C.B.Wilson Pullman	H.Barr Pullman	Whitman	"	"	"	"	50.0	58.0	48.0	55.0
B 29	"	K.Brewer Pullman	"	"	"	"	"	26.0	31.0	31.0	31.0
B 30	"	Scott Getchell Pullman	"	"	"	"	"		37.0	37.0	50.0
B 31	"	Glen Curtis Pullman	"	"	"	"	"	44.0	53.0	57.0	66.0
B 33	M.B.Gilbert, Rosalia	Floyd Olson Rosalia	"	"	"	"	"	21.0	14.0	18.0	16.0
B 40	H.Mewhinney Walla Walla	Orval Mackin Walla Walla	Walla Walla	not classified	"	"	"	26.0	39.0	49.0	40.0
B102	H.P.Woodword Ritzville	K.Wellsardt Ritzville	Adams	"	"	"	"	15.0	8.0	12.0	14.0
B101	"	W. Beckley Benge	"	"	"	"	"	20.0	20.0	22.0	19.0
B140	Robert Cowan Spokane	E.D.Metcalf Mt. Hope	Spokane	"	"	"	"	14.0	17.0	28.0	33.0
B141	"	O.L.Larson Waverly	"	"	"	"	"	26.0	34.0	32.0	41.0
B207	H.Holtz Pullman	Siszell Oaksdale	Whitman	Palouse Si. L.	"	"	"	21.0	31.0	37.0	31.0
B208	"	D.T.Doneen Oaksdale	"	"	"	"	"	34.0		49.0	
B209	"	C.T.Krous Pullman	"	"	"	"	"	27.0	20.0	29.0	35.0
B210	"	Baldwin	"	"	"	"	"	16.0	34.0	39.0	38.0
B 211	"	Roberts	"	"	"	"	"	16.0	19.0	33.0	28.0
B212	"	Lewiston Hill	"	"	"	"	"	13.0			15.0
B213	"	C.Klemgard Pullman	"	"	"	"	"	27.0	31.0	35.0	32.0
C 10	W.W.Pierson Cheney	K.H.Conley Cheney	Spokane	not classified	"	1930	"	37.0	41.0	40.0	40.0
C 23	N.C.McClure Fairfield	C.W.Walters Fairfield	"	Unknown	"	"	"	36.0	38.0	50.0	47.0
C 24	"	C. Tvetly Plummer, Idaho	"	"	"	"	"	46.0	47.0	59.0	47.0
C 40	C.B.Wilson Pullman	C.A.Hood R.3 Pullman	Whitman	Palouse Si. L.	"	"	"	24.0	17.0	21.0	17.0
C 41	"	W. Robinson Pullman	"	"	"	"	"	26.0	44.0	35.0	48.0
C 42	"	H.J.Brewer R.3 Pullman	"	"	"	"	"	26.0	36.0	45.0	53.0

Table 13. (Cont.) Results from Applications of Nitrogen Fertilizers on Soils of the Palouse Formation

PLOT	SUPERVISOR	COOPERATOR	COUNTY	SOIL TYPE	CROP	YEAR	YIELD EXPRESSED IN	POUNDS OF SODIUM NITRATE PER ACRE: CHECK	150	250	350
C 47	M.S.Gilbert Rosalia	Y.T.Hood Spring Valley	Whitman	Palouse Si. L.	Wheat	1930	Bushels	20.0	19.0	12.0	16.0
C 58	M.R.Vereler Waitsburg	Will Hawks Waitsburg	Walla Walla	not classified	"	"	"	34.0	40.0	45.0	53.0
C 59	"	J.Danielson Waitsburg	"	"	"	"	"	30.0	49.0	44.0	55.0
C 61	(1) W.R.Sheff Walla Walla	Ed.Stiller Walla Walla	"	"	"	"	"	53.0	61.0	63.0	66.0
C 62	"	"	"	"	"	"	"	31.0	35.0	39.0	53.0
C 145	R. C. Cowan Spokane	E.D.Metcalf Mt.Hope	Spokane	Unknown	"	"	"	29.0	39.0	31.0	28.0
C 146	"	Frank Clausen Spangle	"	"	"	"	"	42.0	38.0	39.0	52.0
C 154	K.P.Jones Colfax	R.M.Darden Endicott	Whitman	Palouse Si.L.	"	"	"	39.0	34.0	34.0	24.0
C 208	H.Holtz Pullman	Chris Bower Moscow, Idaho	"	"	"	"	"	21.0	33.0	26.0	30.0
C 209	"	R.W.Gwinn Pullman	"	"	"	"	"	15.0	25.0	33.0	34.0
C 210	"	Jim Klemgard Pullman	"	"	"	"	"	32.0	34.0	28.0	38.0
C 211	"	C.T.Kroue Pullman	"	"	"	"	"	21.0	24.0	24.0	30.0
C 212	"	Oscar Collins Pullman	"	"	"	"	"	17.0	28.0	33.0	26.0
C 213	"	Frank Busch Johnson	"	"	"	"	"	26.0	31.0	41.0	47.0
C 214	"	Oscar Collins Pullman	"	"	"	"	"	28.0	39.0	30.0	28.0
D 53	M.C.Farnden Pomeroy	Wayne Boyd Pomeroy	Garfield	not classified	"	"	"	27.0	29.0	32.0	32.0
D 201	H. Holtz Pullman	Ryan	Whitman	Palouse Si. L.	"	"	"	44.0		58.0	
D 202	"	Frank Busch Johnson	"	"	"	"	"	27.0		47.0	
					AVERAGE YIELD IN BUSHELS			28.0	33.0	36.0	37.0
			INCREASE IN BUSHELS PER 100 LBS. FERTILIZER					ADDED	3.3	3.2	2.6

(1) At bottom of slope.

per 100 pounds of fertilizer applied. In general the 150-pound applications may be expected to give the most economical returns in dry years, whereas in years of normal rainfall the 250-pound applications may give the best returns. On the basis of these results, 150 to 250 pounds of nitrate of soda per acre or its equivalent in some other nitrogen carrier applied broadcast to hilltops or upper slopes might be expected to give an increase in yield of approximately three to four bushels of wheat per 100 pounds of nitrate of soda or its equivalent.

CONCLUSIONS

The results of the 265 experiments discussed in this report, although inconclusive in some cases, lead to certain general conclusions.

There is convincing evidence that extreme variations exist in the natural productivity of the soils and that the problem of plant food deficiencies is one that is primarily and distinctly associated with the soil.

It has been demonstrated that the maximum productivity of certain soils in western Washington is so low, even after treatment with relatively large quantities of fertilizers, that the advisability of using these lands for the production of general farm crops is questionable. On the other hand, the natural productivity of a relatively small number of soils is so high that any attempt to increase production further by the use of fertilizers is not economical at the present time.

The large majority of soils investigated are of medium natural productivity and are greatly benefited by fertilizer treatments, which conclusively indicates that the proper use of fertilizers fitted to the particular requirement of these soils is good farm practice.

The proper use of complete fertilizers on pastures on medium producing western Washington soils that are well supplied with moisture throughout the growing season or that can be irrigated economically during the dry season is good farm practice, not only because it greatly increases crop yields, but also because it improves the quality of the pasture grasses and hay in regard to mineral content, notably that of calcium and phosphorus.

Although the classification of soils in groups derived from similar parent material and developed under similar processes of soil formation exhibits specific general characteristics that are helpful in determining related plant food deficiencies, there is a need for further subdivision of the soils in regard to their common characteristics in texture and profile development to be associated with continued studies of the more detailed specific fertility requirements of the soils in the sub-groups.

The full utilization of the results of the fertilizer experiments presented in this report and also of those that will be obtained in the future depends to a large degree upon the amount of information available in regard to the location, extent, and agricultural characteristics of the soils in the state. This information can best be secured through the medium of a state soil survey designed to give an inventory of the soil resources by locating, describing, and classifying the characteristics of the soils suitable for agriculture and for other purposes.

SUMMARY

1. A progress report is made of a state-wide cooperative fertilizer plot project. During the years 1926 to 1931 inclusive, sufficient fertilizers have been shipped to the cooperators for a total of 397 experiments and reliable results of 259 of these and of the six in the pasture fertilizer experiment are given in this report. The history and plans of the experiments are discussed.

2. The soils of Washington have been classified arbitrarily in two large divisions, the leached and thoroughly weathered soils of western Washington, and the arid and semi-arid soils of eastern Washington that are slightly to moderately leached and weathered.

3. The western Washington soils have been subdivided into seven groups and those of eastern Washington into three groups, according to the nature of the parent material from which they are derived and according to mode of formation. The experimental results from each group are presented separately.

4. A study of the results as a whole reveals that there are extreme variations in the natural productivity of the soils. The yields of all the forage crops used for the fertilizer experiments on western Washington soils are classified in three separate groups: first, those from soils of low natural productivity; second, those from soils of medium natural productivity; and third, those from soils of high natural productivity. This classification is used as a basis for the discussion of the results from each group of soils.

5. It is shown that the maximum productivity of the low yielding group of western Washington soils is so small even upon treating them with relatively large quantities of complete fertilizers that the advisability of using these lands for the production of general farm crops is questionable. From a total of 80 fertilizer trials with forage crops, 11 were on these low yielding soils.

6. The natural productivity of a relatively small number of soils is so high that any attempt to increase the yields of general farm crops by the use of fertilizers is not economical at the present time.

7. The results of 69 of the 80 experiments with forage crops on western Washington soils offer convincing evidence that the large majority of soils investigated are of medium natural productivity and, therefore, are greatly benefiited by fertilizer treatments, properly fitted to the particular requirements of the soils. The results of the experiments with alfalfa on the irrigated soils in eastern Washington, notably those in the Ellensburg and the lower Yakima valley districts, lend support to this evidence.

8. There are some indications that legumes grown on certain soils of western Washington were materially benefited by applications of lime. The results with lime as a whole were inconclusive, however, and the experimental work with this material should be continued.

9. The average increase in yields resulting from the use of relatively small quantities of a complete fertilizer on soils in pasture was about 32 per cent for pasture grass and approximately 29 per cent for the hay.

10. With few exceptions, the application of lime, or of phosphate and potash fertilizers to the soil alone or in combinations, resulted in a greater protein, calcium, phosphorus, and potassium content of the pasture grass and hay, showing that the plant nutrient content of pasture grass and hay was increased rather easily by the use of fertilizers.

11. Although the hay produced larger average yields of dry matter than the pasture grass, the latter removed a much greater amount of plant nutrients from the soil. The total requirements of the pasture grass for nitrogen calculated as protein, for calcium, phosphorus, and potassium were approximately 35 to 40 per cent greater than those of the hay.

12. The treatment with lime in combination with phosphate and potash fertilizers resulted in a marked change in the pasture flora on some of the soils. On a lowland soil derived from glacial material, the original flora consisting largely of native brome and fescue grasses and of weeds was changed by this treatment to one comprising approximately 40 per cent clover in the course of two years.

13. The proper use of fertilizers on pastures in western Washington that are on medium yielding soils well supplied with moisture throughout the growing season is considered good farm practice, not only because it greatly increases crop yields, but also because it improves the quality of the grass and hay in regard to mineral content, notably that of calcium and phosphorus.

14. The relatively small number of fertilizer experiments conducted on the irrigated soils, except those in the Ellensburg district, and on the terrace soils in eastern Washington show variable results.

15. The results of 44 experiments with nitrogen fertilizers on winter wheat grown largely on the exposed yellow subsoil of the hilltops and upper slopes of Palouse soils located in the area receiving an average annual precipitation of 18 inches or more show that a treatment with 150 to 250 pounds of nitrate of soda per acre, or the equivalent in some other nitrogen carrier, may be expected to give an increase in yield of approximately three to four bushels of wheat per 100 pounds of this fertilizer when broadcast early in the spring.

16. Although the classification of soils in groups derived from similar parent material and developed under similar processes of soil formation exhibits specific general characteristics that are helpful in determining related plant food deficiencies, there is a need for further subdivision of soils in regard to their common characteristics in texture and profile development in order to determine the specific fertility requirements of the soils in the sub-groups. This need can best be met through the medium of a state soil survey designed to give an inventory of the soil resources by locating, describing, and classifying the characteristics of the soils suitable for agriculture and for other purposes.